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WINTER SECTIONAL MEETING WELL ATTENDED

THE Winter Sectional meeting, held in Cincinnati, January 15 and 16, was most successful and highly profitable, both from the technical and social viewpoint. More than 200 members and guests of the American Society for Steel Treating were in attendance.

From the viewpoint of those in attendance, the high quality of the technical papers presented, and the interesting and instructive plant visitation, this meeting was the equal of any of the previous sectional meetings held by the Society. Much credit is due the members of the Cincinnati chapter for their efficient and capable management of this meeting.

THURSDAY, JANUARY 15

Following the registration and get-together meeting of the members and guests at the Hotel Sinton, Dr. J. Culver Hartzell, chairman of the Cincinnati chapter, delivered an address of welcome and then introduced Arthur W. F. Green, chief metallurgist of the John Illingworth Steel Company of Philadelphia, as chairman of the morning technical session.

There was only one paper presented before the morning session, and this was read by O. N. Stone, assistant chief engineer of the Van Dorn and Dutton Company of Cleveland. This paper was entitled, *"Gearing as a Medium of Industrial Power Transmission,"* and dealt with the making of gears for all types of machinery, with a discussion of the best methods for their production.

Much valuable information was contained in Mr. Stone's paper, and following its presentation, a comprehensive discussion ensued. This paper will appear in an early issue of TRANSACTIONS.

Following the morning technical session, an informal luncheon was served at the Sinton Hotel.

At the afternoon session, Dr. Hartzell introduced H. M. Boylston, professor of metallurgy, Case School of Applied Science, Cleveland, as chairman of this session.

The first paper of the afternoon session entitled, "*Sample Preparation for High Power Photomicrography,*" was presented by R. G. Guthrie, metallurgist, industrial gas department of the People's Gas Light and Coke Company of Chicago. Those who have used this method of inspection no doubt have experienced some difficulty in the preparation of specimens, and the author's paper dealt with the method of producing suitable surfaces for etching prior to microscopic examination. Mr. Guthrie's paper contained a number of high power photomicrographs obtained through the use of both conical and axial illumination. The magnification of the photographs displayed, ranged from 2300 to 15,000 diameters. Mr. Guthrie said that photomicrographs taken at 15,000 diameters had yielded considerable valuable information as to the structural constituents present in steel as a result of heat treatment.

The second paper, entitled, "*Wear and Wear Testing,*" by G. W. Quick and S. J. Rosenberg, of the Bureau of Standards, Washington, presented by Mr. Quick, reviewed many of the recent tests made by the bureau to determine the types of steel best suited for gaging instruments. Although this paper was in the nature of a progress report, the data which had been obtained up to the present time shows that hardened carbon steel resists the wear better than cast iron, manganese steel and stellite.

The third paper of the afternoon was read by T. Holland Nelson, metallurgist for the United Alloy Steel Corporation of Canton, and was entitled, "*Corrosion Resisting Steels of the Iron Carbon Chromium and the Iron Carbon Chromium Silicon Steels.*" Mr. Nelson told of the experiments in which he assisted Harry Brearley of Sheffield, England, in the development of a better gun lining for large caliber guns. The steel which was developed proved to have considerable resistance to ordinary agents of corrosion and has formed the basis of one type of so-called stainless steel.

A general discussion followed each of these papers.

At 6:45 p. m., an informal dinner was held at the Hotel Sinton. The toastmaster, Julian A. Pollak, vice-president of the Pollak Steel Company, was introduced by Dr. Hartzell. An address of welcome was given by Fred A. Geier, president of the Cincinnati Milling Machine Company, who spoke of the early days of Cincinnati, discussing various stages of its development to the modern Queen City.

Response to the address of Mr. Geier was delivered by W. S. Bidle, president of the Society. Mr. Bidle spoke of the importance of Cincinnati's machine tool industry to the modern methods of mechanical production in the United States. He reviewed the development of high speed steel and the resulting development of machine tools to provide for increased capacity and pointed out that the machine tool is only as good as the steel in its cutting tools.

An illustrated technical paper was then given by R. H. Smith, vice-president of the Lamson and Sessions Company of Kent, Ohio, the subject being, "*High Tensile Strengths with Low Carbon Steels*," in which he discussed the results of his researches and the production of high tensile strengths in 0.09 and 0.15 per cent carbon steel. The application which is being made of this development is in the production of high strength rivets and bolts. He stated that rivets and bolts can be made having a tensile strength of 100,000 pounds per square inch with a reduction of area of more than 50 per cent.

FRIDAY, JANUARY 16

At 9 a. m., the members and guests assembled at the Sinton Hotel for plant visitation, making their first visit to the Cincinnati Bickford Tool Company, metal-drilling machinery manufacturers. They then visited the Cincinnati Planer Company and the Cincinnati Milling Machine Company, makers of milling machines, universal cutters and tool grinders, at which plant, luncheon was served. At 2:00 p. m., a tour was made through the Rookwood Pottery Company's plant. Special arrangements were also made for those desiring to visit the plants of the American Rolling Mill Company and the Ahrens-Fox Fire Engine Company. At 6:00 p. m., dinner was served to the members at the Claremont Hotel, Southgate, Ky., as guests to the Andrews Steel Company, after which the company's steel mill was inspected.

FUNDAMENTALS

IN this issue of TRANSACTIONS appears the first of a series of articles by F. T. Sisco, entitled, *"The Chemistry of Iron and Steel."* (Page 197.) This series is divided into four sections. The first includes introductory remarks and a discussion of the occurrence, importance and relationship of the common chemical elements found in iron and steel, as well as the occurrence and relationship of alloying elements in these materials.

The second installment, which will appear in the March issue of TRANSACTIONS, deals with the chemistry of the blast furnace in the manufacture of pig iron, also the chemistry of the Bessemer process in the manufacture of Bessemer steel.

The third installment, to be published in the April issue of TRANSACTIONS, discusses the chemistry of the acid and basic open hearth and electric processes for the making of steel.

The fourth and final installment of this series will appear in the May issue, and deals with the chemistry of wrought iron and crucible steel production. In addition, a comprehensive discussion of the ordinary defects usually observed in iron and steel is included.

This series of articles is in keeping with the endeavor of TRANSACTIONS to provide its readers with articles dealing with the fundamentals as well as the advances in the art of metallurgy, metallography and heat treating. In addition to the publishing of papers dealing with researches, investigations and studies of a more or less technical nature which has characterized and placed TRANSACTIONS on such a high plane in the scientific field, a more extended amount of space will be devoted in the future to a discussion of the fundamental and educational problems as distinguished from the strictly research and investigational papers. Readers of TRANSACTIONS may look forward to a more detailed account of these new activities of the A. S. S. T. in a later issue of TRANSACTIONS.

COMMENTS ON THE MAKING AND USE OF ALLOY TOOL AND SPECIAL STEELS

By J. A. Mathews

Abstract

This paper constitutes a general resumé of the development of the tool steel industry. The various melting methods used in producing tool steel are briefly touched upon, and a discussion of the various elements used in the production of a high grade product is included.

The author discusses the subject of chemical specifications as a basis for the purchase of tool steels, pointing out that such a method of buying tool steel places an unnecessary burden upon the buyer.

WE sometimes forget that culture follows, it does not precede, commerce. It was so in the civilizations of pre-Christian times, and through the Middle Ages. It was true in Elizabethan days and it is true in our own age, which posterity may with some justification refer to as the Tin-Elizabethan age, since Mr. Ford has produced his ten-millionth "Tin Lizzie." In the early days of our own country, there was little time for science or letters, while in the same period in France or England, science and letters flourished. Many of the fundamental laws of astronomy, physics and chemistry were discovered in France and England, while our people were conquering the wilds of the new country. We developed our tobacco, lumber, iron and fur trades before we had time to devote to leisurely investigation.

The modern era of machinery, and especially automatic machinery, has been largely responsible for our munificent educational endowments for higher learning, while the average learning of the masses has made even more wonderful progress, yet the well-meaning welfare workers "register pain," to use a movie term, at the thought of the soul-shriveling monotony of working automatic machines. We wonder if any of them ever reflect as to whether they would rather use one of Eli Whitney's cotton gins for eight hours, or pick cotton seed by hand, when twelve or fourteen

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A paper presented before the Boston Convention of the Society, September, 1924. The author, John A. Mathews, is vice-president of the Crucible Steel Company of America, New York.

hours are required to pick one pound. Which is the more monotonous, to manufacture clothing in a modern sanitary factory with power machines, or to sew with a domestic needle for hours, as of old by the light of a tallow dip, to earn a mere pittance? Our distressed friends overlook the law of compensation whereby as the result of the modern factory system, the working men may enjoy everyday things that were unavailable to princes in Queen Elizabeth's day. Workers in factories at least have the advantage of social intercourse with their fellows, a vast improvement over the monotony of the cottage industries in days when wages were regulated by statute, migration was prohibited, hiring was done by the year and the unemployed had to accept service or imprisonment. In that period, labor was, in very great measure, illiterate. Today labor is vastly better off, and as a reward for short hours in a factory, has money enough to provide reading matter, music, more and better clothes, houses and food, than labor ever enjoyed before. Every laborer today is an employer, for while he is working at his machine, others in many parts of the world are working for him to produce his flour, tea, coffee, sugar, fruit, and even his entertainment. Improved transportation and communication make all this possible. The local failure of a crop today does not mean malnutrition and starvation, followed by plague and pestilence, for all in the immediate vicinity. It is scarcely believable that any thinking person desires a return to the industrial life of the Middle Ages, with its ignorance and oppression.

The history of civilization might well be written in terms of man's progress in the making and the use of tools. The modern era has brought about great advancement in education, comfort, health, and happiness. No doubt there is an industrial as well as a natural law of the survival of the fittest, and some day we shall produce a generation that will not be so easily influenced by the agitator and muckraker to ignore the benefits of labor, industry and thrift. Never since the Psalmist's day could we more fervently say with him, "Oh, that men would praise the Lord for all His goodness to the children of men."

It is more than two hundred years since Reamur published his classic researches on carburizing and decarburizing and to the best of his ability endeavored to give an explanation of the molecular behavior of iron and carbon. It is over a hundred years since Michael Faraday published his research on alloy steels. Berthier wrote on the same subject at about the same time, but Faraday's report may be considered as the beginning of the study of alloy steels. He investigated to a considerable extent alloys with the rarer metals, but also made some chromium and nickel alloys. His purpose in conducting the investigations was: (1) to ascertain whether any alloy could be artificially formed, better for the purpose of making cutting instruments than steel in its purest state; and (2) whether any such alloys would, under similar circumstances, prove less susceptible to oxidation;—new metallic combinations for reflecting mirrors were also a collateral object of research. We are still at work trying to improve cutting qualities; it was ninety years before "stainless steel," which has revolutionized the table cutlery business, was evolved and various Government departments are still at work along the line of Faraday's "collateral object of research"—metallic mirrors. Mt. Wilson Observatory has recently been supplied with some stainless steel for reflectors, which were ground flat within one-tenth of a wave length of light, 1/500,000th of an inch over a six-inch disc. To Faraday, nickel steels were but synthetic meteorites. Notwithstanding Faraday's and Berthier's pioneer work, we do not find that alloy steels were commercially produced until Mushet invented air-hardening tool steel about seventy years ago, and alloy steels for engineering purposes date from the late eighties.

The difficulty with a general paper on tool steel arises from the breadth of the subject. What shall be included? Are plowshares and harrow discs tools? Is any kind of a spring—hair-spring, clock-spring, etc., a tool, even though made of tool steel? Magnets, annular bearings and balls are customarily made from crucible or electric steel, but are they tools? Fortunately, our discussion will be limited to alloy steels, yet that is a very large subject, when both the manufacture and metallurgy are to be considered, but these two subjects can hardly be separated.

MELTING PROCESS EMPLOYED

We will also limit our consideration to crucible and electric alloy steels. The methods of melting are too well known to call for detailed description. The crucible process is a melting process and no attempt at purification is made. To get a good product, one starts with good raw materials of an average composition which will yield after melting a homogeneous product of the desired composition. While no purification in the usual sense of removing sulphur or phosphorus is attempted, yet important reactions are going on within the crucible after all the material is molten, notably a reaction between carbon, silicon and manganese and the oxides in the form of scale or dissolved oxides in the raw material. The completion of these reactions is controlled by the time and temperature at which the material is held after complete melting.

In the electric furnace we have both melting and refining going on and at the end we have to a greater or less extent the period of reaction similar to that of the crucible, but with the difference, that the slags are almost universally basic. One would naturally expect the conditions presented by an acid crucible in contact with molten metal containing oxides, to be more certain and efficacious than the conditions of a basic lining and slag in contact with the same kind of metals. One cannot be as certain as to the complete refinement of an impure charge in the electric furnace as one is of a pure charge in a crucible furnace. It is partly because of these differences that the writer has stated that seldom is a process discovered that cannot be improved upon. Crucible steel is an exception to this rule. This earliest process makes the best steel and has never been improved upon. This statement refers to quality of product and not to economic differences in cost of production, the recovery of scrap values and the ability to produce from low or medium grade materials, a medium or high grade refined steel. The electric furnace product is, under the best conditions of operation, the nearest approach to crucible quality that has appeared in the 180 years of "genuine crucible cast steel." It may be as many years before it displaces crucible steel in the esteem of discriminating users.

Whichever melting process is employed the end sought is the same, viz., to produce from a heterogeneous mixture of raw materials a homogeneous product practically free from slag and inclusions of all kinds. This end is most readily accomplished in the crucible process, but it may also be accomplished in the electric furnace with sufficient care in the operation. We know from actual experience that the electric furnace product can be made sound and clean, but that it always has been made so may be questioned. About eight years ago the author stated that the electric process would go through a period of disfavor on account of the fact that furnaces were being installed faster than skill in operation could be acquired and this prediction came true during the war period. Electric furnaces were installed by those who had no prior experience in steel making, apparently with the idea that the electric furnace provided the cure-all for all manner of defects which steel is capable of showing. Another class installed electric furnaces based upon prior experience in open hearth steel, and for such it was quite easy to be convinced that the electric process yields a high grade product. The third class which installed electric furnaces were those who had had prior experience in the manufacture of crucible steel. They approached the problem from quite a different point of view because all of their training and experience was based upon the manufacture of the highest grade of steel that can possibly be made. They were not so easily convinced as to the merits of electric steel, but applied to the operation of electric furnaces all the tried methods of crucible steel practice which might assist in producing in the electric furnace a product comparable with crucible cast steel. We must always look to the melting department for the basis of fine steel production. The sins of omission and commission there cannot be atoned for by any subsequent operations in hammering, rolling, annealing or inspection. They may, however, be obscured to some extent but will crop up in the hands of the ultimate user.

The term "alloy steel" is not as accurate as it should be to describe the products we are discussing, for we must bear in mind that all steel is an alloy of iron with at least five ordinarily recognized elements. The term "special steel" is little better, because it applies equally as well to carbon steel as to alloy steel and refers to any type of steel particularly suited for a special use, such as screw stock, gun barrel steel, rail steel, etc. In writing the recent tariff, the Ways and Means Committee undertook to define alloy steel for tariff purposes by setting arbitrary limits. According to their definition steel containing silicon and manganese, which are always present, is not considered an alloy steel unless they are in excess of one per cent. In the case of other elements, such as nickel, chromium, tungsten, etc., an arbitrary limit of six-tenths of one per cent was placed, but this was obviously not based upon any scientific analysis of the subject, since special properties may be secured by the addition of much less than six-tenths of one per cent of certain elements to carbon steel, as for example, in chromium and vanadium steels.

It may interest you to know that in no tariff within the author's memory has the distinction been made between the fine steel industry and the tonnage steel industry, with the single exception of one Democratic tariff bill. In all other cases, the rates of duty have been as high or higher for the cheaper products as for the high grade products. The public generally and even the users of steel do not seem to recognize this fundamental distinction. In terms of volume, the manufacture of tool steel does not exceed one-half of one per cent of the total steel industry of the country. The investment in plant per ton of product is about five times as great as it is in the manufacture of ordinary commercial steels. The output per man is about one-fifth as great, while the incoming freight in a tool steel plant is from six to eight times as much as the outgoing product. The industry is a handicraft industry, wherein human skill is employed to a much greater degree than in commercial steel production. The use of expensive mechanical equipment for yielding large tonnages is not applicable in the manufacture of fine steel. While it is an art, yet it is an art to which scientific control may be readily applied, and within the last twenty years, great advances have been noted in the application of scientific methods to the control of the industry, which was formerly largely empirical.

COMPARISON OF FINE STEEL AND TONNAGE INDUSTRY

The distinction between the fine steel industry and the tonnage industry may be likened to the manufacture of Rolls-Royce cars, in which every known refinement in engineering skill is employed in the production of the highest grade product that it is possible to make, regardless of expense, while in the manufacture of Ford cars, large quantity production at the lowest possible cost is the aim of the manufacturer. Or again, it may be compared to the mining of diamonds versus anthracite coal. Chemically, they are related, but one is a small quantity business at a high price and the other is a quantity business at a relatively low price. The public has often confused price per pound with profits, and thus we have seen many companies embark in the manufacture of fine steel and attract capital which could have been much more profitably employed in the manufacture of commercial steels.

In the beginning of this century tool steel mills manufactured only four or five qualities. Each plant made a Standard, Extra and Special grade of carbon tool steel, an air-hardening steel, either of the manganese-tungsten type similar to the original Mushet steel, or of the tungsten-chromium or molybdenum-chromium type which succeeded it in the years immediately prior to the invention of high speed steel. Some mills also produced a tungsten steel generally known as "finishing steel," "double special," etc. This steel is of very high carbon and retains a keen cutting edge, which in conjunction with its extreme hardness makes it particularly suitable for finishing cuts and for use in cutting extremely hard materials at low speeds. With the advent of the new century there came the development of electric smelting furnaces and the alumino-thermic process for the manufacture of ferro-alloys and pure metals. This made availiable for the use of the steel makers a superior quality of these materials and induced a great deal of experimentation in the manufacture of alloy steels for different purposes. The result is, today, that aside from the four or five original types of steel, the products of the various mills are not standardized. Innumerable compositions are on the market, but we may expect that time and experience will show which of these is deserving of a permanent place and which will be discarded.

Chromium and manganese are the elements which confer upon carbon steel in the greatest degree, the property of hardening in oil; in other words, of hardening by a retarded rate of cooling. They also confer the property of deep hardening and maintain in combination the carbon which is sometimes found to be precipitated in the form of graphite or temper carbon in very high carbon steels. Nickel finds very little application in tool steels, and silicon, while useful, is rarely present in large amounts. Twenty years ago, we were afraid of chromium steels because of fear of breakage in hardening. This may have been due in part to the inferior quality of the ferro-chromium formerly available, but it was more largely due to our lack of knowledge as to methods of manufacture and treatment of such steels. Chromium steels up to two per cent are regularly made today for water quenching. They find application in the manufacture of tools, permanent magnets, balls and races, and to some extent in the manufacture of tools for hot work.

MAGNET STEELS

The writer first devoted serious attention to the manufacture of permanent magnet steels in this country and by the installation of suitable testing equipment—the first to be installed in a steel works laboratory—was able to produce a dependable grade of permanent magnet steel which displaced the foreign steels that had formerly been used. In addition to the use of magnetic testing in connection with permanent magnet steel, we attempted to investigate the relation of the magnetic qualities to the mechanical qualities in the hope of finding a non-destructive test which could be applied to the finished article of manufacture rather than to rely upon destructive tests on samples of material supposed to represent the article of manufacture. This was before the term "magnetic analysis" had been introduced. In the course of our investigations, we found that certain types of steel show greater magnetic retentivity when quenched in oil than when quenched in water, even though their hardness in the oil-quenched condition was not as great as when water-quenched. This was contrary to all previous ideas in reference to the question of permanent magnetism, which was generally believed to be greatest in any steel when that steel was in its hardest physical state. In general, steels of the type known as "oil hardening," display this property to the greatest degree. The result of this investigation was that when the war interfered with our tungsten supply and raised the price to an almost prohibitive one, we were prepared to furnish a chromium magnet steel practically identical in its properties with the tungsten magnet steel that had been standard for many years. The steel that we employed was not a new product, but an old product which we found to possess unexpected properties when subjected to magnetic tests.

The result of these investigations has been of very great benefit to the electrical industry for it gave to it a satisfactory permanent magnet steel at a much lower cost than tungsten steel and at a very critical time when tungsten had to be conserved for high speed steel production. It was found that by using the new material no change in size or design of magnets or of apparatus was necessary, so nearly was it a duplicate in magnetic characteristics of the old tungsten standard.

While on the subject of magnet steel, mention should be made of Professor Honda's wonderful cobalt permanent magnet steel. This product is of more than ordinary scientific interest because it shows a coercive force some three to four times as great as that of the best tungsten standard, and also possesses good residual strength. There are few alloy steels which show a higher coercive force than tungsten magnet steel, and they are usually very low in residual strength. Hardened high speed steel would make a very permanent magnet but a weak one. The very high cost of the Honda product makes it of somewhat uncertain commercial value.

A few of the other alloy steels of special interest may be described briefly. There are entirely too many different types to list them all. We may next mention the corrosion resisting or stainless steel—the kind Faraday was seeking a hundred years ago.

STAINLESS STEEL

The commercial product known as "stainless steel" is due to Harry Brearly's efforts and investigations. In its present form it is of greatest importance in the manufacture of table and kitchen cutlery. It is a steel of about 0.35 per cent carbon and 13.50 per cent chromium. Other compositions in wide variety have been made, but for a steel that can be readily forged, hardened and tempered for cutting purposes, this general type has been found most suitable. In carbon steel we look for free cementite when the carbon exceeds 0.90 per cent. In stainless steel, free carbides are detected in either the annealed or hardened state if the carbon is above 0.30 to 0.35 per cent. When the carbon greatly exceeds this amount, the carbides are very apparent and are difficult to put into solution upon heating. A temperature that is high enough to accomplish this purpose is apt to produce a brittle steel and unless the carbides are absent after quenching, the stainlessness is impaired. Properly hardened, stainless steel is not attacked by 1.20 sp. gr. cold nitric acid. When a carbon content lower than 0.35 per cent is present, we obtain less hardness by quenching and the lower the carbon the less the need for quenching at all, so far as increasing resistance to stain is concerned. Nevertheless, in very mild carbons, as 0.10 per cent, very marked changes in physical properties may be produced by suitable heat treatment, and hence we have a very interesting material for engineering requirements where great hardness is not needed. Such material is more readily drop-forged, stamped and machined than the higher carbon product used for cutlery. Within a range of from 0.10 to 0.40 per cent carbon we can secure tensile qualities of from 60,000 to 200,000 pounds per square inch with good ductility. Stainless steel when cooled from a temperature of 1700 degrees Fahr. will air-harden very greatly in light sections. It is not greatly softened by drawing the temper at temperatures up to 900 degrees Fahr. and in drawing the temper it is obvious that the ordinary "temper colors" cannot be relied upon, for the very nature of the alloy is to resist oxidation at low heats, to which "temper colors" are due. This alloy shows excellent qualities, much better than might be expected by basing our judgment upon Brinell hardness. With hardened stainless steel it is quite possible to produce soft spots by careless grinding practice, and such spots will stain. Stainless steel possesses high strength at elevated temperatures. In this respect it is much superior to ordinary carbon or alloy steels and very nearly equal to high speed steel.

Another type of corrosion resisting alloys has been developed by C. M. Johnson. It has been known for many years that the high nickel alloys, say from 25 to 35 per cent, were resistant to oxidation but they are not especially resistant to acid attack and they do not show especially high physical characteristics. Messrs. Brearly and Haynes have covered the possibilities of the high chromium steels very exhaustively, while Mr. Johnson has produced a most interesting series of steels, combining various high percentages of both chromium and nickel together with other elements to meet special conditions. He seems to secure the good qualities of both elements and to eliminate the faults of each. These alloys show extraordinary resistance in many instances; for example, they are tough and ductile after cooling in liquid air and by quenching from high temperatures they become tougher the higher they are heated, say up to 2250 degrees Fahr. They resist all attempts to magnetize them and show a high resistance to the passage of an electric current. They not only resist nitric acid attack but also sulphuric acid, glacial-acetic and all the ordinary fruit and organic acids, and sulphur mine-water, sea-water, etc. They do not require hardening in order to be stainless and heat resisting. They are more resistant to most of the ordinary reagents than the non-ferrous alloys and are of less specific gravity and greater strength and hence of greater interest as engineering materials to meet unusual requirements. One type of this steel has been very successfully used for periscope tubes; its high modulus of elasticity and proportional limit make it superior to the non-ferrous products for such a use and its resistance to sea-water corrosion is quite satisfactory. They possess unusual strength and fatigue resistance up to 1600 degrees Fahr. The investigations that led up to this most interesting series of steels have covered a period of several years but the results have justified the effort both from the scientific and practical engineering point of view.

Antedating the various alloy steels already described and of great value to the arts was the introduction into this country over fifteen years ago of the first oil-hardening, non-distorting tool steel. It was the author's opinion at the time it was introduced that this improvement in tool steel was second only in importance to the invention of high speed steel. The extraordinary results that may be obtained by the use of such a steel in making of parts that must fit perfectly after hardening are too well known to need further mention. It is interesting to note that this steel expands on heating just as does any other steel and the amount of this expansion is no small amount, something over an eighth of an inch per foot over a range of 1500 degrees Fahr. A steel that expands say 125 thousandths on heating and comes back just 125 thousandths on quenching and tempering is an object of more than ordinary interest in making intricate punches and dies, gauges and intricate tools.

HIGH SPEED STEEL

Of all the alloy tool steels, the one which is the most discussed is high speed steel. As an article of manufacture it has received a degree of attention far beyond its importance to the tool steel industry. It reminds one of the popular interest in coal tar dyes. A little dye goes a long way in tinting fabric and a little high speed steel goes a long way in removing metal. There may be some question as to whether its invention has been an asset or liability to the tool steel industry. Its importance to the industrial world, however, can scarcely be estimated. It has revolutionized machine tool design and shop practice and has created untold wealth—for its users.

The fundamental discovery of the property of red-hardness by Taylor and White made the use of high speed steel possible. The steel in use in their day was the old-fashioned air-hardening steel containing about 1.75 per cent carbon, 8.0 per cent tungsten and 4.0 per cent chromium. In some cases, 4.0 per cent molybdenum replaced the tungsten. With the announcement of the Taylor-White process, the whole tool steel world—the United States, England, Germany and Austria, seemed, with one accord, to start in producing steels with much less carbon and much more tungsten. Thus, the early high speed steels sprang into being at a bound in 1901 and 1902. Tungsten from 12 to 20 per cent or molybdenum from 6 to 9 per cent were used in the earlier high speed steels; the carbon was generally below 1.0 per cent and the chromium about as at present. Such steel was a tremendous advance over air-hardening steel, if given the proper high heat treatment.

About this time the author became interested in the possibilities of vanadium. Vanadium was first quoted at $72.00 per pound and there was none in the country. A little later the United States acquired a "visible supply" of about thirty pounds and half of the available supply was procured. Investigations were immediately begun as to its effects on both tungsten and molybdenum high speed steels, and it was found that it tripled the efficiency of the steels then on the market. The author has reason to believe that European metallurgists were working with vanadium quite as early or earlier than the experiments in this country. The introduction of vanadium was the first and greatest improvement in high speed steel and the addition of cobalt was the second. The cobalt high speed steels may be considered as special-purpose steels. There was a great controversy between English and German metallurgists as to who invented cobalt high speed steel. There is some doubt whether the argument was ever settled, and there are also several American patents covering its use. Other elements in addition to the regular tungsten-chromium-vanadium combinations have been tried with varying success, such as molybdenum, uranium, zirconium and tantalum.

High speed steel is an alloy of at least nine elements, six of them common to all steels, and at least three special elements—tungsten, chromium and vanadium. In some cases it contains from one to three more. Of the regular constituents most of them are known to exist in two or more forms or combinations. This makes a very complex material from both a practical and scientific point of view. We know very little, indeed, as to the inter-relations of these elements or to what extent one of them replaces another. It is fairly well known that with lower tungsten, high vanadium is needed to make an equivalent product, but aside from this relationship there is much to be learned. However, there is a tendency on the part of consumers to write general chemical specifications for the purchase of high speed steels. They seem to desire a general specification covering all high speed steel whether it is to be used for hot or cold work, lathe tools, blanking dies, drills or cutters, and for cutting such different materials as hard and soft steels, non-ferrous metals, hard fibre, bone, chilled and grey iron, etc. It is difficult enough to write a specification for steel for one specific purpose, but to write a general one at this time, is quite out of the question.

CHEMICAL SPECIFICATIONS

The wise councils of the past are ignored, notably those of Dr. Charles B. Dudley—the father of specifications for engineering materials. Twenty years ago he warned that a specification was not an occasion to show how much we know; that it should contain the least number of restrictions necessary in order to secure for the buyer what he wants and to inform the seller what is wanted; that it should not be needlessly burdensome or difficult of fulfilment. For a number of years one of the departments of the Government has endeavored to buy high speed steel on a basis of chemical specifications. Bidders are given an option of two types of analysis—the high tungsten-low vanadium type, and the low-high vanadium type. Actually, however, steel is purchased on the basis of very protracted cutting tests, costing both the tax-payers and the bidders many thousands of dollars. In other words, what is desired is cutting ability and not analysis. Their chemical limits for the two types of steel are quite broad—so broad, in fact, that steel of inherently good and inherently bad analyses may both come within their limits. Therefore, the chemical limits imposed mean nothing. They dare not rely upon them as determining quality but depend upon a cutting test, which is as it should be. However, they may resort to chemical limits as a rejection test without any knowledge as to whether the steel rejected is good, bad or indifferent for cutting tools. The spirit of Dr. Dudley is not in such specifications. As some homely philosopher said, if you want to make a house look yellow, use yellow paint. If you want lathe tools, look to cutting ability and not to analysis.

Let me quote a sentence from Bain and Jeffries' recent article on the "Cause of Red Hardness in High Speed Steel." (*Iron Age*, Vol. 112, p. 805, September, 1923.) After referring to the wide variation in composition of high speed steels, they say:—"These figures merely tend to emphasize the fact that the thermal and mechanical history of a bar of steel is so much more significant than its composition (within certain limits) that the effect of small variations in composition is relatively unimportant."

As an index of quality, chemical analysis is a frail reed to lean upon. It is not difficult to produce low sulphur and phosphorus steel, say below 0.02 per cent, in basic open hearth furnaces of large size; much electric steel is exceptionally free from these elements but not exceptionally good, while a great deal of very excellent crucible steel is not below 0.025 to 0.03. This is especially true of the English and Styrian steels formerly held in high esteem by many American users of tool steel. There are many skilled in the handling of tool steel whose judgment of quality based upon visual examination of a fracture is more to be depended upon than an analysis report.

In many plants the chemist has no chance of attracting the attention of the boss unless he sets up a fuss occasionally about one or two points of carbon or one or two thousandths of one per cent of sulphur or phosphorus. Please do not think I do not appreciate skillful, accurate analyses or a well-balanced composition in a steel, otherwise sound and clean. It is the abuse and not the use of analyses that I am discussing—the chemical crimes that are committed. The basing of judgment of quality upon a chemical report as compared with the judgment based upon a steel sense, born of experience in handling steel, is like trying to imagine what a stranger on the other end of a telephone is like as compared with a conversation in person with an old friend.

As I have said before, the best specification that can be had is that based upon mutual confidence and respect and a full understanding of service conditions. When we can secure such cooperation we are glad to select by actual analysis, and not by wide ranges, a steel particularly suited to a particular use. In some cases, we select carbons to a three or four point range, or chromium to a range of ten or twenty points and we watch the whole balancing of the entire group of elements. It is by confidence and cooperation that results like these may be attained. They never could be attained by buying to ordinary chemical specifications. There is still too much to be ascertained as to the physics of high speed steel, both in its manufacture and use, to warrant our wasting time with wide-open chemical ranges. For one hundred years the tool steel mills have assumed the responsibility of furnishing steel suitable for a given purpose and their warranty of the steel furnished is based upon that foundation. When the customer tells the maker what to furnish, he should assume full responsibility and release the maker from his customary warranty. Just why users wish to assume a needless responsibility I have never been able to understand.

From an observation of several years, and from discussion with other manufacturers, the author is of the opinion that a very large percentage of the steel complained of, or rejected upon inspection, is for the reason that it does not conform to some arbitrarily set chemical limits, or to some new, little understood, unstandardized physical test, rather than because the inspector knows definitely that the steel is unsuited to the purpose for which it was bought.

For fear that I may be considered "reactionary" may I quote the words of that greater thinker and scholar of Cambridge, Mass., President Emeritus of Harvard University, Dr. Charles W. Eliot, who recently said:[1] "It is obvious that standardization has become a dangerous adversary of progress in both education and industry." I am glad to know that what I have considered a private opinion is not my exclusive opinion but is shared by such an eminent man as Dr. Eliot.

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[1] The reference appears in the discussion of this paper.

We have mentioned the principal types of alloy tool steels that constitute the chief items in the advancement of the art during the past twenty years. There are many more of lesser importance which need not be described in detail. It is a pleasure to know that many of these new products have been given to manufacturers as a result of researches conducted in plants which the author has had the honor to serve.

RESEARCH AND ADVANCEMENT

A few words in regard to advancement in our knowledge of tool steel and methods of handling and studying it may be in order. First, as to the state in which carbides exist in hardened and tempered steels. Heyn investigated the residue left by dissolving hardened and tempered steels in diluted sulphuric acid. He found no carbon in the form of cementite in steels tempered below 750 degrees Fahr. He concluded that troostite, therefore, contained no cementite but some hypothetical form of carbon. Osmond disputed this conclusion and suggested that the cementite may be in such a finely divided state that it is dissolved by the acid. Saito, by the magnetic analysis method of Honda, concluded that cementite is precipitated from solution in martensite and largely dissociated into its elements, iron and carbon, but that by further tempering to 625 degrees Fahr. the cementite is reformed, but he confirms Heyn in finding no free cementite in residues from steel tempered below 750 degrees Fahr. Honda and Murakami found that pure cementite ceases to be ferromagnetic at about 420 degrees Fahr., while double iron-tungsten-carbide, such as is found in low tungsten steels, is ferro-magnetic up to 750 degrees Fahr.

Professor Honda and his associates have made valuable contributions to our knowledge of the carbide changes in steel by the method of magnetic analysis, and have shown that electrical conductivity and thermal methods confirm the magnetic results. By these methods changes in constitution that may not be detected by microscopic examination are readily detected, as for example, the precipitation of cementite upon tempering hardened steels below 390 degrees Fahr. This tempering is accompanied by almost no softening of the steel. This point corresponds to the temperature that the writer noticed many years ago in connection with the aging of permanent magnets by tempering. It used to be customary to japan certain instrument magnets followed by baking. In many cases the magnet was injured in the baking operation and it was found that up to 390 degrees Fahr. the coercive force is not seriously lowered by heating, but above that range there is a very great lowering in the coercive force or retentivity. There is some lowering brought about even below 350 degrees Fahr., but it is gradual.

These carbide changes are accompanied by volume changes and if the temper is not drawn the changes take place spontaneously and very slowly, accompanied by an evolution of heat. Many years ago, Professor Carl Barus investigated these spontaneous changes in a series of steels that were kept under observation for several years. The electrical conductivity method was used. More recently, Professor Brush, of Cleveland, investigated the same problem by observations on the heat evolution and found the amount of heat to be greatly in excess of that which could be accounted for by the release of strains set up by hardening. The subject was again investigated by Matshushita who used the method of actual measurements of length changes in rods of steel from low to high carbon. He found in low carbon steels that a lengthening took place during the first 50 hours after hardening. In medium steel there was lengthening for a few hours followed by shortening, while in hypereutectoid steel shortening always occurred. This was for steels quenched in oil. When quenched in water, even 0.44 per cent carbon steel showed expansion followed by contraction, while the 0.75 per cent carbon and eutectoid steels only contracted. The elongation is explained as resulting from an incomplete Ar_1 transformation and the contraction as the result of precipitation of carbide from the martensite. This separation may require months or years at room temperature but can be produced in a few hours by a mild tempering at the boiling point of water. These investigations are of the utmost importance in connection with movements in hardening and cracking, after hardening.

The author's axiom in regard to heat treatment is: uniform conditions give uniform results. It may be the original history or condition of the steel, or it may be the variation in subsequent handling that produces non-uniform results, but steel will not behave erratically when all conditions are uniform. The factors that may affect distortion, cracking and change of volume are numerous; as the result of some hundreds of hardening experiments and many thousands of measurements made by the writer years ago, he regards the following as the variables to be considered:

1. The composition of the steel
2. The original form and dimensions
3. The temperature from which quenched
4. The time at full heat
5. The original physical condition of the steel, such as hot-rolled, annealed, semi-annealed, hard-drawn or cold-drawn annealed
6. The time and temperature of tempering.

As the result of the study of these variables it appears that, other things being equal, the original condition of grain affects the resulting changes of form after hardening; that above the Ac_1 point the coefficient of dilatation increases proportionately with the carbon content and for all carbon contents the rate of dilatation increases with the temperature; that the specific gravity is diminished by cold work and by quenching.

As was stated at the beginning, the manufacture of tool steel is an art and not a science; the handling of tool steel by the user should be scientific. Apparatus is available for the control and measurement of temperature, for thermal, electrical, magnetic and microscopic analysis, and for the testing of the finished product in many ways, to control its uniformity. We cannot make steel absolutely to a fixed analysis as you make interchangeable parts on an automatic machine to precise measurement. We have fixed standards to work to, but in crucible steel we must rely upon the knowledge of our raw materials and frequent analyses of the finished ingots. It is manifestly impossible to analyze completely some 800 to 1000 small ingots per day. Even the carbon content has to be determined by the appearance of the fracture and a good man can do so with as good average accuracy as the laboratory is likely to maintain. It is average results with the product over a period of time that makes reputation for tool steel brands, rather than the occasional exceptional record, and it is remarkable the consistent record for uniformity that the old established firms are able to maintain. The industry is one requiring infinite patience, care and watchfulness and the problems presented are innumerable. It is a business of perpetual detail yet one of great fascination, and it is becoming more so with every addition to our scientific knowledge of this wonderful alloy. The author's injunction to every user is—study your steel. The work is inspiring and the results will amply repay the time and labor.

We know that all the myriad compositions, structures and combinations of physical properties displayed by this wonderful substance—steel—are governed in their behavior by definite laws of science. There are laws still to be discovered and we are appealing for that higher appreciation of fine steels which calls for vision, a steel sense, and a scientific imagination. Whether we know all the laws or not, there is a fundamental truth to be remembered in the handling of steel—uniform conditions give uniform results.

The American Society for Steel Treating was founded at the right time—not only to enjoy the benefits of recent progress in the science of metallurgy but also to participate in further research, and, in fact, to lead in all that which makes for permanent advancement. No other society presents such a clearing house for ideas and such fallow ground for the seeds of cooperation and mutual endeavor along conservative and constructive lines. We have the support of the Bureau of Standards, the Bureau of Mines, and other governmental agencies, and we also have a duty to support them to the best of our ability. At our local, sectional and national meetings the shop man and the mill man, the practical man and the theoretical man, the producer and the consumer, the plant chemist and metallurgist, and the university chemist and metallurgist meet. Under such circumstances, with straight line thinking and a desire to know the truth before committing ourselves individually or collectively to the untried and unproven, with a sincere desire to view matters from the other fellow's point of view, this Society must and will accomplish great things.

This paper should not be construed as in any way opposing specifications in general. I have pointed out some of the difficulties of general specifications, in which it is attempted to cover too much ground in a single specification for material that may be put to a wide variety of uses. This is particularly true in regard to specifications for tool or high speed steel for other than those of the individual user of steels for a particular purpose. General specifications should meet three requirements. They should be (1) of benefit to the purchaser, (2) of benefit to the consumer and (3) of benefit to the public and the basis of a specification should be that of the most important factors which define the usefulness of the article for its ultimate purpose. It is a relatively simple matter to write a specification for an article or commodity which is used in exactly the condition it leaves the maker's hands. Tool steel is rarely used in its original form as sold. It may be forged, machined, annealed, hardened and tempered. It is put into a thousand designs for thousands of purposes. Its true measure of worth is its ultimate serviceability for a given purpose. The design of the tool, the conditions of its use, the manner of heat treatment and equipment used and the skill of the hardener are not within the control of the steel maker. The inspection tests made under a specification should be capable of exact duplication by different investigators and be capable of mathematical expression. Tests which give results that are mere matters of opinion and that cannot be exactly stated, lead to constant friction and misunderstandings. Specifications are too often made as a display of knowledge and as a basis for an inspection department which confers prestige upon the head of the department. Once written they acquire a sort of sanctity like the Ten Commandments or our Constitution before the Eighteenth Amendment. They are difficult to amend and hence retard progress, and with tool steel there must be continual progress, since a greater output and lower tool cost is the end sought. The output desired from a tool is, from the user's standpoint, practically unlimited, since the user is always desirous of increasing the output from his tools and hopes they will never wear out. This can scarcely be accomplished if the quality of the steel is fixed by terms of general specifications in which both the producer and the consumer have had a voice. These are nearly always a matter of compromise and do not represent the best material that it is possible to make. Their terms must be such that purchasing under them is not restricted to a single source and when based upon ranges of chemical analyses it is quite possible to have a greater variety of material within the range than would be obtained from material representing the middle of the range, for the more important elements even though one or more of the minor elements were out of the range. The problem is an extremely difficult one and it is to point out the difficulties and the necessity for greater care and thoughtfulness in the writing of specifications that the author has touched upon the subject of specifications at all.

Discussion of Dr. Mathews' Paper

CHAIRMAN BURGESS: I am sure I express the sentiment of all of us when I say that we are most indebted to Dr. Mathews for his beautiful and masterly presentation of this survey, historical, practical and theoretical, of what we might call the special tool industry.

In his address, Dr. Mathews quoted from a letter which Dr. Eliot sent to the New York *Times* some months ago, and I wish to say that I had somewhat the same reaction that Dr. Mathews implied.

I wrote to Dr. Eliot immediately upon reading this letter and called his attention to a possible misunderstanding that it might incur on the part of the engineering public. I realized, of course, he was emphasizing the undesirable features of standardization in education, and as far as industry was concerned, he was referring specifically to the repetitive operations in industry, but not at all in any sense to the simplification and standardization of engineering products. I was, of course, particularly interested, first as Director of the Bureau of Standards, and then as President of the American Society for Testing Materials, and I sent him a copy of my Presidential address[1] on the subject of "The Trend of Standardization," and President Eliot heartily endorsed the sentiments expressed therein.

Dr. Eliot's letter, the "Blight of Standardization," as published in the New York *Times*, August 17, 1923, and Dr. Burgess' correspondence pertaining thereto, follows:

> "A new blight is afflicting education and industries in the United States, particularly the educational part of industries. Its name is standardization, and there is a very general movement to give it application in a great variety of American activities. The blight seems to have started in the industrial domain. To save time, and therefore money, and to increase the productiveness of a given plant, the movements of the individual operative were carefully studied with a view to reduce the number of his movements and changes of posture, and to increase the automatic and repetitive quality of his work. The object was larger production at lower cost, and this

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[1] Published in *Proceedings* of American Society for Testing Materials, Vol. 23, 1923, page 40.

object was gained, but the inevitable result was the destruction of the interest of the workman in his work. For the life-long interest of the handworker in the varied products of his skill was substituted the intolerable dullness of tending machinery on a standardized "stop-watch" program.

"Soon standardization began to affect the school and college programs, the conditions of admission to college, and the qualifications for degrees. It limited injuriously freedom of election of studies in both school and college. It also affected the method of instruction in every school or college course, particularly in the lower or more elementary courses. Thereby, the liberty of the individual teacher, particularly in the lower grades, was restricted, and the expedient liberties of pupils and students were also confined.

"It is obvious that standardization has become a dangerous adversary of progress in both education and industry. The ideal in education is to develop the utmost possible variety of individual attainment and of group attainment; just as the true goal of democracy is the free development of the utmost variety of capacity in the individual citizen. Uniformity in the attainment of skill and therefore in earnings, leads not to joy in work but to discontent and unhappiness in the worker. The true educational goal is the utmost development of the individual's capacity or power, not in childhood and adolescence alone, but all through life. Fixed standards in labor, in study, in modes of family life or of community life, are downright enemies of progress for the body, mind, and soul of man. That doctrine is as true in churches, courts, and legislatures as it is in schools and factories. It is sometimes desirable to suggest minima as respects age, intelligence, or productive capacity, but never maxima. It will be for the happiness of the American people to look carefully into the effects of standardization in both the national education and the national industries. It has already gone too far. Although some pecuniary economies can be effected by standardizing processes in both schools and factories, their physical and moral effects are unquestionably bad. As soon as any process in State or Church proves to be injurious to the physical or mental quality of the population a genuine democracy should set to work to modify or suppress it.

"The reason that the majority of the American people is today unchurched is that the various Christian denominations or church institutions from the first century to the nineteenth set up fixed standards of belief and practice based on what were supposed to be final revelations. Since experimental science began, about 150 years ago, to contribute powerfully to the progress of mankind, those fixed standards in the Church have become discredited among thinking people; but since the religious instinct is universal and irrepressible in man, a diligent search is now going on for a Church free from standardization. This search and the co-operative management of the fundamental industries are the most promising efforts of the twentieth century.''

Northeast Harbor, Me., Aug. 14, 1923.

Dr. George K. Burgess' letter to Doctor Eliot.

August 27, 1923.

President Charles W. Eliot,
Northeast Harbor, Maine.

Dear Doctor Eliot:

I have read with much interest your letter in the New York *Times* of Friday, August 17th, under the caption the ''Blight of Standardization.'' Although I agree with many of your statements it occurs to me that some of your readers may take your statements as a condemnation of all phases of standardization as applied to industry. This, I am sure, is far from being your thought.

I enclose a copy of recent address by me on ''The Trend of Standardization,'' delivered before the American Society for Testing Materials, in which certain phases of the standardization problem are considered briefly from the points of view of elimnation of waste and as a basis for progress in industry.

Very truly yours,
(Signed) George K. Burgess

Dr. Eliot's letter to Doctor Burgess.

Northeast Harbor, Me.,
August 30, 1923.

Dear Dr. Burgess:

In my short article called the ''Blight of Standardization'' published in the New York *Times* of Friday, August 17th, I had not at all in mind the kind of standardization which the American Society for Testing Materials or the American Engineering Standards Committee practices. I was thinking about the effect on operatives or working-men who work under what is called scientific management, that is, under severe restrictions as to their motions and postures and obliged to conform to the speed of the machines they tend. I think, however, that the standardizing work of the American Engineering Standards Committee is pushed too far towards uniformity, without taking enough account of the great diversity of transportation and marketing conditions. Thus, a freight car to carry fifty tons may be the best standard for the Pennsylvania Railway, but not for the Northwestern Railway; or a hammer of the best pattern for widespread use on a large variety of objects may not be the best for narrow use on a highly specialized material.

> I agree completely to what you say of the value "of concerted action looking to simplification in type, design, and dimensions, and standardization of materials, practice, and performance." No one who has observed what you call our present industrial chaos can have any doubt about the value of the concerted action you describe. I recognize, too, that "scientific management" increases production and therefore the wealth of the country; but it seems to me to increase, on the whole, the volume of human wastes and of industrial discontent.
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> I hope that the prophecy contained in the last paragraph of your address on "The Trend of Standardization" will be fulfilled.
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> Sincerely yours
> (Signed) Charles W. Eliot

A. H. D'ARCAMBAL: During the past five years we have been purchasing all of our carbon tool, alloy, and high speed steel under specifications calling not only for chemical but also for physical properties. This has resulted in the production of cutting tools of uniformly good quality. Also, increased production has resulted, due to the steel being more easily machined than steel formerly received from the mills under brand names. Our hardening loss has also been reduced a very great extent since purchasing steel under specifications. We are paying more for these steels due to purchasing them under specifications than we would if purchased by brands, but we have found by careful analysis that the former way is the more economical one in the long run.

Quite often one reads articles by representatives of the steel companies condemning without reservation the purchasing of steels under specification. They usually state that when the buyer of the steel specifies the material they (the buyer) accept full responsibility. We have found that the mills we are buying from co-operate with us to the greatest extent and they do not seem to take that attitude. That is, if we run into trouble, they have their representatives come and help us, and they are willing to co-operate with us to the greatest extent, although we do specify the chemical and physical properties of the material purchased.

T. D. LYNCH: We have had a similar experience to that of Mr. d'Arcambal, and we find it of the greatest importance to know the chemistry of our steel, and even if we buy a brand, we want to know the chemistry of that brand, in order to know how to properly heat treat it in the different forms that we want to use it. Dies, as you appreciate, particularly those for stampings of sheet steel, electric sheets, etc., are of a great variety of forms and shapes, and in order to study those and to study their expansions and contractions, we must know the chemistry of the material, and the relation of one shipment to another, so that we may govern our heat treatment accordingly. I certainly think that the question of specifications for tool steel is a practical one for large corporations. It may or may not be at the present time for the small consumer.

MICROSTRUCTURAL FEATURES OF SEVERAL METEORITES[1]

By J. S. Vanick

Abstract

The structural features of several meteorites which represent massive bodies of single-grain, high-nickel iron, are described. An effort is made to correlate the special features with the corresponding ones of common occurrence in annealed, or heat treated, or deformed steels in the light of the more comprehensive and more detailed information available in regard to the steels. From this point of view: (a) the divorce of the high nickel-iron constituent, tænite from the eutectoid conglomerate plessite, is mentioned for a group of meteorites containing the eutectoid plessite; (b) the direct precipitation of the high nickel-iron, tænite from the low nickel-iron kamacite is considered; (c) the probable instability of the point marking the minimum solubility of tænite in kamacite, is discussed.

INTRODUCTION

METALLIC meteorites offer a fascinating field for study and speculation. The special structural features which they possess are uncommon in alloys of the corresponding chemical composition. Metallic meteorites consist chiefly of iron, nickel, and cobalt, with phosphorus, sulphur and carbon present as the principal impurities. These elements in an alloy made by ordinary metallurgical processes would be expected to form a homogeneous solution in the liquid which when solidified would retain the homogeneity of the liquid state and appear as a solid solution of a single structural constituent.

The single constituent form of structure seldom occurs in meteorites. Benedicks[2] had developed the angular, Widmanstatten form of structure by slowly cooling iron-nickel alloys. The Widmanstatten structure had been reproduced in other alloys but never in the extremely coarsened form in which it is developed in certain meteorites. Unusually large segregates are not uncommon

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[1] From a thesis presented to George Washington University in partial fulfillment of the requirements for the degree, Master of Science (1922).

[2] *Revue de Metallurgie.* 7, 1084, 1910 and 8; 85; 1911.

The author, J. S. Vanick, is in the research department of the International Nickel Co., Bayonne, N. J.

in meteorites. Such segregates are often visible in the macrostructure of a polished section.

Typical components of structure have been named by mineralogists, following the usual custom. The composition of some of these structural components in familiar terms, follow:

Name	Composition	Remarks
Kamacite	Nickel iron	less than 7 per cent nickel
Taenite	Nickel iron	more than 28 per cent nickel
Plessite	Nickel iron	Kamacite-taenite eutectoid
Troilite	Iron sulfide	
Schreibersite	Nickel-iron phosphide	
Lawrencite	Iron chloride	

To these might be added the names of components familiar to the physical metallurgist.

Name	Composition
Austenite	Solid solution of gamma iron and added elements
Martensite	Solid solution of alpha iron and added elements
Pearlite	Eutectoid of 0.9 per cent carbon and alpha iron
Ferrite	Pure iron (alpha)

Following the mineralogists' preference for classification based upon crystal habit,[3] the nickel-iron meteorites have been divided into 3 groups:[4]

A. HEXAHEDRAL IRONS: showing cleavage parallel to the faces of a cube and lamellæ due to twinning, of a cube on an octahedral face. On etching they show Neumann lines.

B. OCTAHEDRAL IRONS: showing plates parallel to the faces of an octahedron. On etching, these show Widmanstatten figures. The lamellæ vary in thickness from 0.1 to 2.5 millimeters and the meteorites have been subdivided further for this reason.

C. MASSIVE IRONS. These are "amorphous" irons which show none of the above features.

From a metallurgical standpoint, this classification is not wholly satisfactory in view of the association of Widmanstatten or Neumann bands with the octahedral and hexag~~ona~~l groups, respectively. A description in a following paragraph mentions

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[3] Bulletin 94, U. S. National Museum, p. 4, 1916.

[4] The position is here arranged to conform to the direction of increasing nickel content from A to B.

hedral

Neumann lines traversing a Widmanstatten band, in two directions, in the Casas Grandes meteorite which is classified as octahedral. Subsequent discussion emphasizes the probable occurrence of hexahedral markings in octahedral irons. Obviously, the presence or absence of the bands or lines is not an index of the form of structure.

A less involved form of classification would place the nickel-iron type of meteorite upon a composition basis in which the quantity of the important chemical elements that the meteorite contained, would determine its position in a simple binary or ternary alloy system. The less important ingredients might then be discussed with respect to their influence upon the parent system. This method is invariably used in metallurgy in the study of alloy systems. Mineralogists make the error of calculating the composition as determined by chemical analyses into compounds such as schreibersite, lawrencite, kamacite, etc., without regard to the fact that a large proportion or, perhaps, all of the essential elements which compose the calculated compound, are in solution or combined in other than the proposed form.

The constitution of most nickel-iron meteorites is best illustrated in Guertler's diagram,[5] which outlines the composition ranges occupied by the three principal constituents, kamacite, plessite and tænite.

Pfann[6] offered very good illustrations of the compounds represented in the diagram, after studying the structure of meteoric irons containing 8 to 27 per cent nickel. His work supported some earlier observations and offered microstructural evidence to show that:

a. Kamacite was a solid solution of nickel and iron containing 6 per cent or less nickel;

b. Plessite was the eutectoid of tænite and kamacite which formed either macro- or micro-plessite, depending upon the state of division of the components of the eutectoid;

c. Tænite was a solid solution of nickel in iron, containing more than 27 per cent nickel.

The above terms are adopted in the following description, although it is admitted that the solubility maximum of 7 per cent nickel for kamacite and the minimum of 28 per cent nickel for the tænite still lack general acceptance. Plessite zones, as will be subsequently shown, may vary widely in composition, depending upon the degree of segregation to which the two principal components have submitted.

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[5] *Zeit. Phys. Chemie*, Vol. 74, p. 428, 1910. Benedicks places the eutectoid plessite line at approximately 360 degrees Cent. in place of 0 degrees Cent. This temperature lies in the tempering range, of temperatures favorable for the transformation of gamma to alpha iron. The fact must not be lost sight of, however, that a corresponding change to some degree, may occur in water quenched nickel steels by immersing the quenched specimen in liquid air.

[6] *International Zeit. für Metallographie*—Vol. 9, p. 65, 1917.

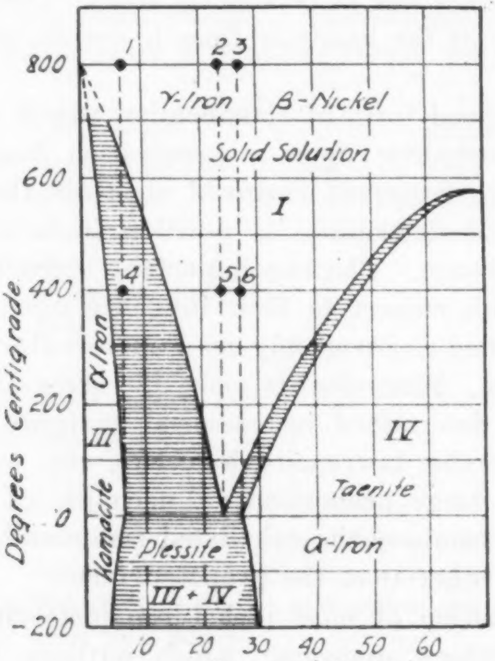

Fig. 1—Guertler's Diagram.

Materials and Method

The work described in the following paragraphs was undertaken with the expectation that the application of modern methods of metallography might reveal new features of interest. Further, hope was held that evidence of the presence of nitrides, chlorides, oxides, carbides or other metallic derivatives of corresponding gases might be detected in the comparatively coarse structures.

For this purpose, six meteorites, two of which had been analyzed for their gas content, were selected from the collection at the U. S. National Museum, and submitted to a careful metallographic inspection. The selection was made by Dr. G. P. Merrill, Head Curator of Geology, at the National Museum, whose help the author wishes to acknowledge.

The composition of the meteorites, as previously determined,[7] follows:

	Casas Grandes	Toluca	Dalton	Mt. Joy	St. Francois	Cranbourne
Iron	90.47	89.66	94.66	93.80	92.68	
Nickel	7.742	7.90	4.80	4.80	6.97	
Cobalt	.604	.63	.34	.51	.52	
Sulphur	.029	.14	.025	.01	.01	
Phosphorus	.166	.24	.081	.19	.34	
Carbon	.177*		.006			
Iron oxide	.794	Other elements less than .05 per cent				
		Gases—percentage by volume**				
Co		.12				1.13
Co_2		1.32				.04
N_2		.10				.63
H_2		.27				1.63
CH_4		.04				.16
CL_2		...		.255		...

*0.032 per cent graphite; 0.145 per cent combined carbon.

**These determinations made by heating crushed specimens and evacuating gases do not account for combined compounds and, therefore, do not represent total quantity of gaseous elements, present.

The composition and general structure of these meteorites, as well as the crystal habit as exposed in the macrostructure, are described in Bulletin 94 of the U. S. National Museum. Some mention is made in other scientific literature of the macrostructure of the Casas Grandes, Toluca and Mt. Joy meteorites.[8]

The microstructure of the six specimens permitted a separation into 3 groups, the general features in each group being common to the individuals in the same group. These groups contained the following:

		% Nickel	Crystal* habit.
I.	Casas Grandes	8.3	Octahedral; lamellae, 5 to 1.0 millimeters thick
	Toluca	8.5	Octahedral; lamellae, 5 to 1.0 millimeters thick
	Dalton	5.1	Octahedral; lamellae, 5 to 1.0 millimeters thick
II.	Mt. Joy	5.3	Hexahedral; brecciated
	St. Francois	7.5	Octahedral; lamellae, 1.5 to 2 millimeters thick
III.	Cranbourne		Octahedral; lamellae, 1.5 to 2 millimeters thick

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[7] As reported in Bulletin 94, U. S. National Museum and Publication 106, Carnegie Institution, p. 22-26.

[8] Catalogue of the meteorites of North America. O. C. Farrington, National Academy of Sciences, Memoirs, Vol. XII.

MICROSTRUCTURAL FEATURES

Structure of Group I Specimens

The application of Guertler's diagram of the iron-nickel system in meteorites to the compositions of the meteorites of Groups I and II would fix the position of the Dalton and Mt. Joy specimens in the hypo-eutectoid or kamacite field, while the others would be in the plessite-kamacite field. Pfann's metallographic work, confirming Guertler's diagram, would lead to the expectation of corresponding microstructures. Actually, the structures of the Mt. Joy and St. Francois specimens contained isolated patches or particles of tænite in a matrix of kamacite, while the remaining specimens, excluding Cranbourne, showed the eutectoid plessite in a coarse, Widmanstatten banded, matrix.

The macrostructure of the 3 meteorites in Group I reveals the kamacite bands arranged in the characteristic Widmanstatten pattern. Figs. 2 and 3 illustrate the latticed pattern. The remaining specimens did not develop this coarsened structure. The inter-band filling of the lattice should contain the eutectoid, plessite. Plessite areas are, consequently, broad and angular in shape and need not be confused with the slightly darkened bands of kamacite which are usually straight, long, and parallel sided.

In the meteorites of Group I the eutectoid plessite adopts a wide variety of forms which seem to illustrate the progress of its dismemberment by the segregation or divorce of its components. Fig. 4 shows the position of thin tænite bands in a eutectiform area which is distinguishable in the macrostructure of the Toluca specimen. Figs. 5 to 9 represent areas which were chosen for the purpose of illustrating the apparent selective segregation of the tænite that occurs within the eutectoid patches. Figs. 5 and 6 are, perhaps, the nearest approach to a normal eutectoid structure which the plessite zones in this series of specimens attained. Fig. 12 shows the darkened core that is prevalent in many of the tænite bands. Pfann has called this core "micro-plessite," as a designation for the eutectoid in which the state of division of the components is extremely fine. Particles of tænite are distinguishable in the darkened core and indications of other constituents are visible. The core appears to consist of the remains of a shrunken tænite band in which the impurities of an initially

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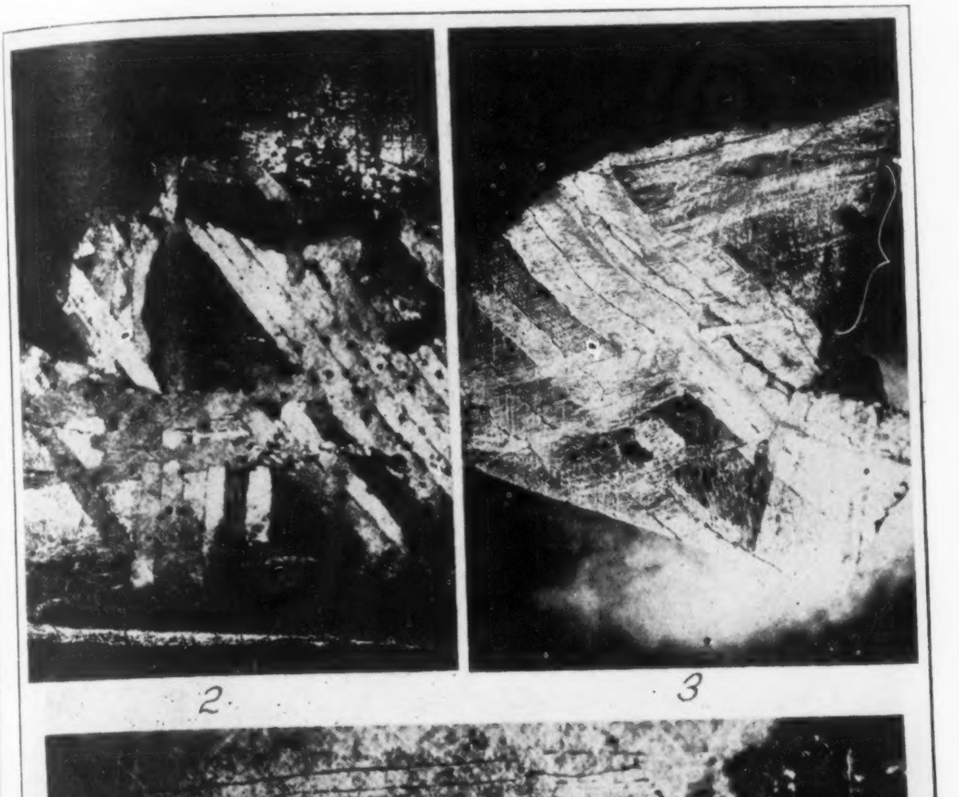


Fig. 2—Coarse Bands in the Dalton Meteorite. 3x. Fig. 3—Coarse Bands in the Toluca Meteorite. 2x. Fig. 4—Films of Tænite Between Kamacite Bands in Eutectiform Area of Fig. 3. 8x. Triangular Area Indicated in Fig. 3. Oblique Illumination.

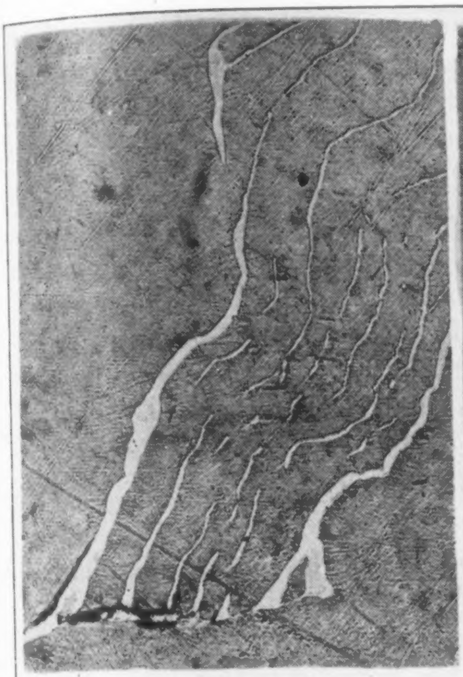
large eutectoid area are concentrated. Similar bands showed the isolated needles or barbs that remained embedded within a tænite area wherein the tænite divorce had been more thoroughly accomplished. These markings bear a strong resemblance to martensitic barbs and, therefore, readily suggest the presence of carbon-rich segregates in the tænite residue. Etching the coalesced tænite of a dismembered eutectoid area in boiling sodium picrate produced the effect shown in Fig. 10, which seemed to support the suggestion of the presence of carbon particularly in view of the selective darkening of portions of the tænite envelope in contrast to the darkening of the entire enclosure when the usual etching reagent was used, as for Fig. 9.

Widmanstatten bands and Neumann bands and lines occur in both Group I and Group II specimens. For this reason, a description and discussion of these structural markings will be set forth later.

Structure of Group II Specimens

The combination of the Mt. Joy and St. Francois specimens into a single group was based upon the absence of the eutectoid plessite and the similarity in the form of deposition of tænite particles in the kamacite matrix. The composition of these meteorites is not appreciably different from that of the previous group, yet the absence of the eutectoid and the freedom from contamination which the tænite particles exhibited upon etching, suggested that the factors active during the formation of Group II structures were not the same as those active for Group I. Factors which might bring about the observed effects are: alloy content; gas content; and differences in the rate of cooling, in particular the length of sojourn at the "tempering" or "subeutectoid" temperature.

In general, the microstructure of the Group II specimens revealed a comparatively homogeneous matrix studded with rhombic particles of tænite. Figs. 11 to 16 illustrate the form which the tænite precipitation adopted in these specimens. A feature peculiar to the Mt. Joy specimen was the presence of large, angular patches of tænite. Fig. 21 shows the large bodies of tænite which occurred along the fissures or near the surface of the Mt. Joy specimen. These tænite patches within the matrix probably



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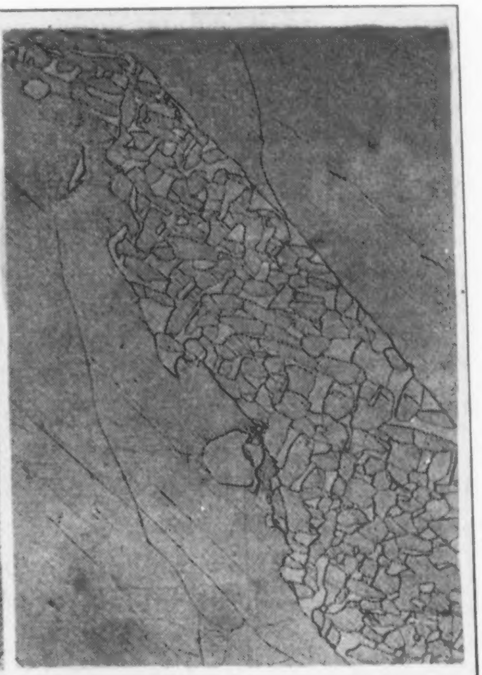

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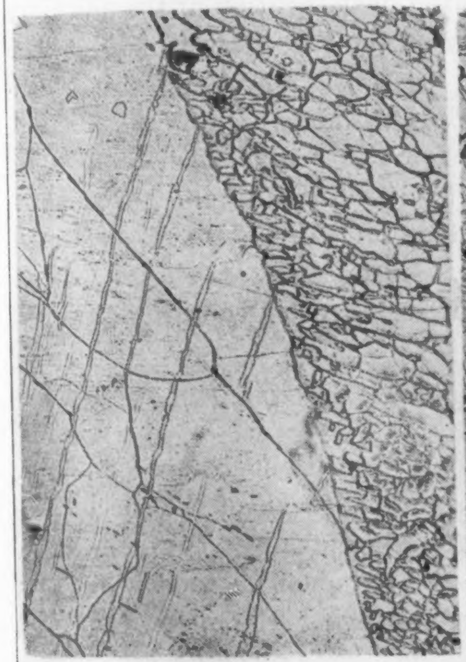

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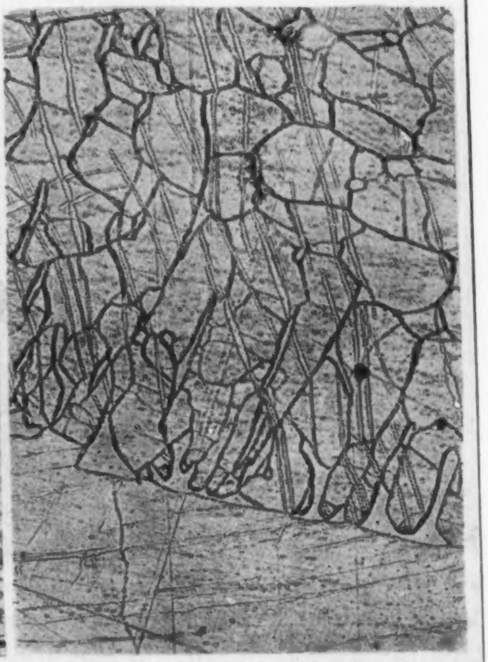

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Fig. 5—Eutectiform Area in Toluca Meteorite. Fissured Along Kamacite, Tænite Junction. 50x. Fig. 6—Eutectiform Conglomerate in Casas Grandes Meteorite. 100x. Fig. 7—Plessite Patch Consisting of Fine-Grained Kamacite Interspersed with Tænite Particles. Neumann Bands Traverse the Matrix. 50x. Fig. 8—An Area of Fig. 7, Showing Neumann Bands Traversing the Fine-Grained Area. 100x. Figs. 6, 7, and 8 are Structures Developed in Casas Grandes Meteorite. All Specimens Etched in 2 Per Cent Nitric Acid in Alcohol.

represent the consolidation of many of the small crystals. Where tænite lines the fissures or adjoins the surface of the meteorite, its position there is analogous to that of ferrite or cementite in hypo- or hypereutectoid steels and the motivating force is, doubtless, similar.

Structure of the Group III Specimens

The Cranbourne meteorite which constituted the single entry in this group differed distinctly from the usual nickel-iron types. This specimen was selected because of the information available in regard to its gas content. On the other hand, no record of a chemical analysis of its metallic constituents had been found. Its unusual structure would lead to the expectation of an unusual composition.

The structure is that of a hypoeutectic cast iron. Figs. 17 and 18 illustrate several types of the cementite plus austenite eutectic which forms the matrix of the specimen. The eutectic is interspersed with dendrites of the pro-eutectic austenite, as shown in Fig. 18. Within the dendrites, the pearlitization of the austenite is usually complete, but examples of the persistence of unaltered austenite also occur.

The intricate structural markings which a high carbon content introduces, makes a search for the presence of compounds of other elements tedious and difficult. Sulphur and phosphorus were tested for, and oxides located, but any evidence of nitrogenous compounds for which this specimen was chosen, would have been obscured in the complex, cast-iron, structure.

Oxides, Nitrides, Phosphides, Sulfides, Etc.

Oxides occur in three noteworthy positions in the structure of the six meteorites; first, as surface films on all of the specimens; second, as envelopes, encasing particles of tænite; third, as cores within the austenitic dendrites of the Cranbourne specimen. The surface oxidation doubtless occurred during the passage of the metallic mass through the earth's atmosphere. The heat produced by friction raised the surface temperature enough to permit oxidation. The oxide so formed was rapidly eroded from the surface. All of the specimens showed a thin film of oxide which remained adhering to the surface. Oxidation also progressed along

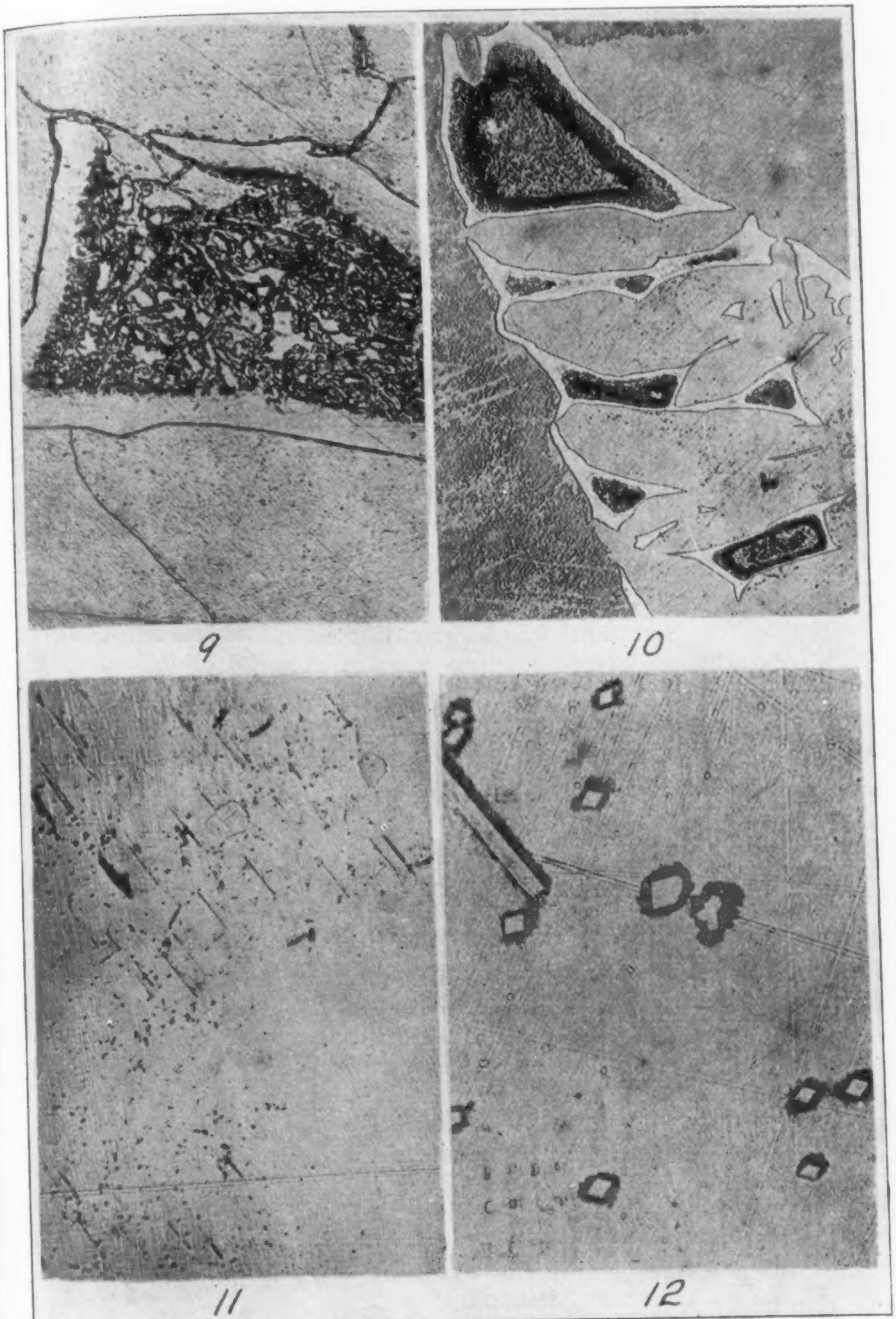
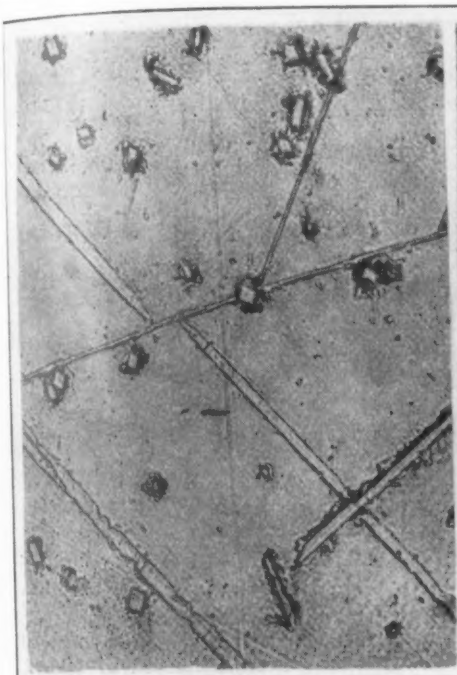


Fig. 9—Plessite Residue Enveloped by Tænite. Casas Grandes Meteorite. 500x. Fig. 10—A Plessite Area, Similar to that of Fig. 6 or 9, after Etching in Boiling Sodium Picrate. Casas Grandes Meteorite. Darkening Probably Caused by Carbon in the Eutectoid Residue. 50x. Fig. 11—Minute Spots and Plates in the Unetched Surface Prove to be Oxide Enveloped Rhombs and Plates of Tænite. Mt. Joy Meteorite. 50x. Fig. 12—Same as Fig. 11. 500x. All Specimens Etched in 2 Per Cent Nitric Acid in Alcohol, Except Fig. 10.

the fissures within the metallic mass, as might be expected. In the Mt. Joy specimen, where bodies of tænite adjoined the fissure walls, the superior resistance of the tænite to oxidation was demonstrated by the casing of oxide with which such tænite particles were enveloped. Fig. 21 shows this feature. The infiltration of oxide from the surface of the meteorite into one of the fine-grained, laminated areas of tænite was also apparent. In such a structure the tænite sheets were enveloped by oxide and an indication of a selective oxidation of the kamacite in preference to tænite was expressed in the brightened edges of the kamacite islands which were enclosed by the oxide. The unoxidized, original structure probably had the appearance of the patch shown in Fig. 5. Oxidation along the tænite-kamacite junctions suggests inadherence there at the relatively high temperatures at which oxidation progresses. The apparent disregard which Neumann bands show for these junctions would indicate that the inadherence disappears at lower temperatures and is no longer manifest at temperatures favorable for Neumann band formation.

The occurrence of oxide compounds or oxygen initially in solution in a meteorite appears to be demonstrated in the oxide enveloped rhombs of tænite which are embedded in the Mt. Joy specimen. The absence of either a continuous or intermittent connection between the surface oxide and this group of oxide enveloped particles suggests the presence, initially, of the oxide or oxygen within the specimen. Fig. 12 illustrates a typical occurrence. The St. Francois specimen which is, in general, similar in structure to the Mt. Joy specimen, contained comparatively few of the oxide enveloped, tænite rhombs in its matrix.

Oxidation in the Cranbourne meteorite appeared to show a preference for the dendritic austenite which, in addition, was severely pitted. Examples of dendritic pitting appear in Figs. 17 and 18. The pits or voids may have been produced by the evolution of dissolved or entrapped gas. Subsequent oxidation may have filled some of the voids with oxide. Much of the iron oxide which occurs below the oxidized skin, is embedded within the dendritic cores. Indications of a replacement by selective oxidation of eutectoid lamellæ in the interior of a dendrite were found. The imprint of pearlitic lamellæ in the oxide would indicate that oxidation had occurred below 700 degrees Cent.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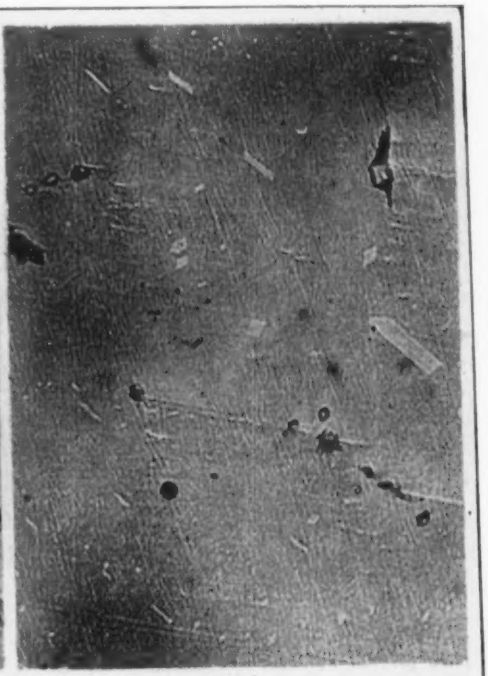
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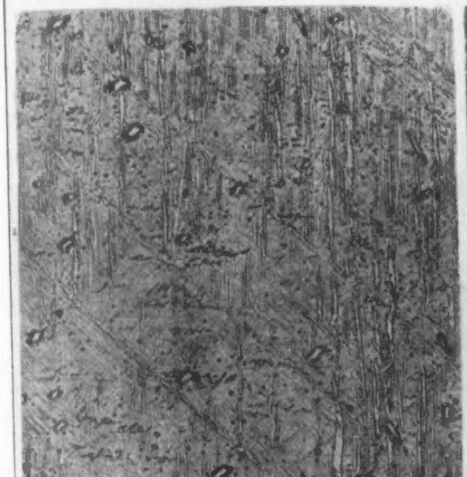
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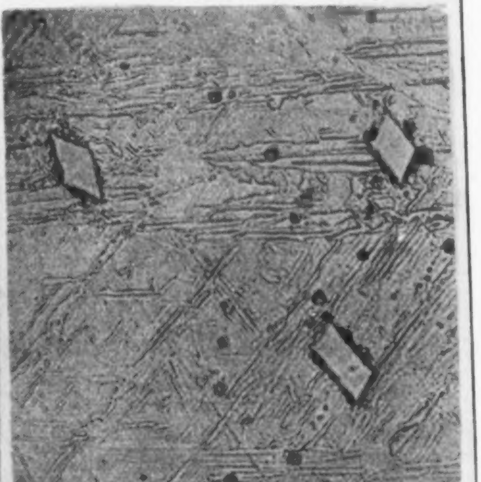
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Fig. 13—No Relation is Apparent Between the Tænite Rhombs and the System of Neumann Bands which Traverse this Surface. Mt. Joy Meteorite. 500x. Fig. 14—Brilliant Rhombic Particles of Tænite are Visible in the Unetched Matrix. St. Francois Meteorite. 100x. Fig. 15—Tænite Particles Assume an Orientation Independent of the Directional Course of the Neumann Bands. St. Francois Meteorite. 100x. Fig. 16—An Area Similar to that of Fig. 15 at a Higher Magnification. Note Absence of Oxide Envelope about Tænite Rhombs in Comparison with Figs. 12 and 13. Figs. 13, 15 and 16 Etched in 2 Per Cent Nitric Acid in Alcohol.

(1292 degrees Fahr.) at temperatures at which pearlite is capable of retaining its rigidity. The preferential oxidation of the austenite dendrites was doubtless assisted by their lower carbon content. The proximity of the oxidized dendritic cores to the surface of the meteorite and the heavy film of oxide over the surface associates the source of the above effects with the usual surface oxidation.

In view of the abundance of surface oxide, the passage of the hot metallic mass through the earth's atmosphere might be expected to provide favorable conditions at least near the surface for a combination of iron and nitrogen, although the temperature of the entire mass did not reach the fusion point in its approach to the earth. Pure nitrogen does not combine with iron at temperatures below the melting point of iron but the presence of nitrides in fusion welds has demonstrated the ability of molten iron to absorb nitrogen from the air during the relatively short interval of time during which the molten drop had access to the nitrogen of the air. If such a combination took place during the flight of the meteorite some confirming evidence would be expected in the appearance of nitrides in the microstructure. No definite evidence of the presence of nitrides appeared.

In a search for the position of phosphorus segregates, assuming their probable presence, the copper solution etching reagents and heat-tinting were tried without significant results. The simultaneous darkening of the tænite core and the kamacite matrix failed to indicate the presence of a phosphorus segregation. The high-nickel, tænite areas always resisted the copper deposit or the oxidation coloring upon heat tinting. The resistance of iron solutions of nickel, oxygen or oxide, and phosphorus to the usual phosphorus reagents made this test a failure. The test simply revealed the tænite rhombs or patches in greater contrast than developed by the usual reagents. The sectioned specimens which were examined showed no evidence of the presence of the phosphorus-rich constituent, schreibersite.

The sulphur print method of testing for sulphur revealed a few small spots, approximately the size of a pin head, in the Mt. Joy specimen, and a delicate web of spots throughout the Cranbourne surface. The remaining specimens showed very few or no sulphur spots. No trace of large nodules of the iron sulphide (troilite) were detected in the small specimens which were examined.

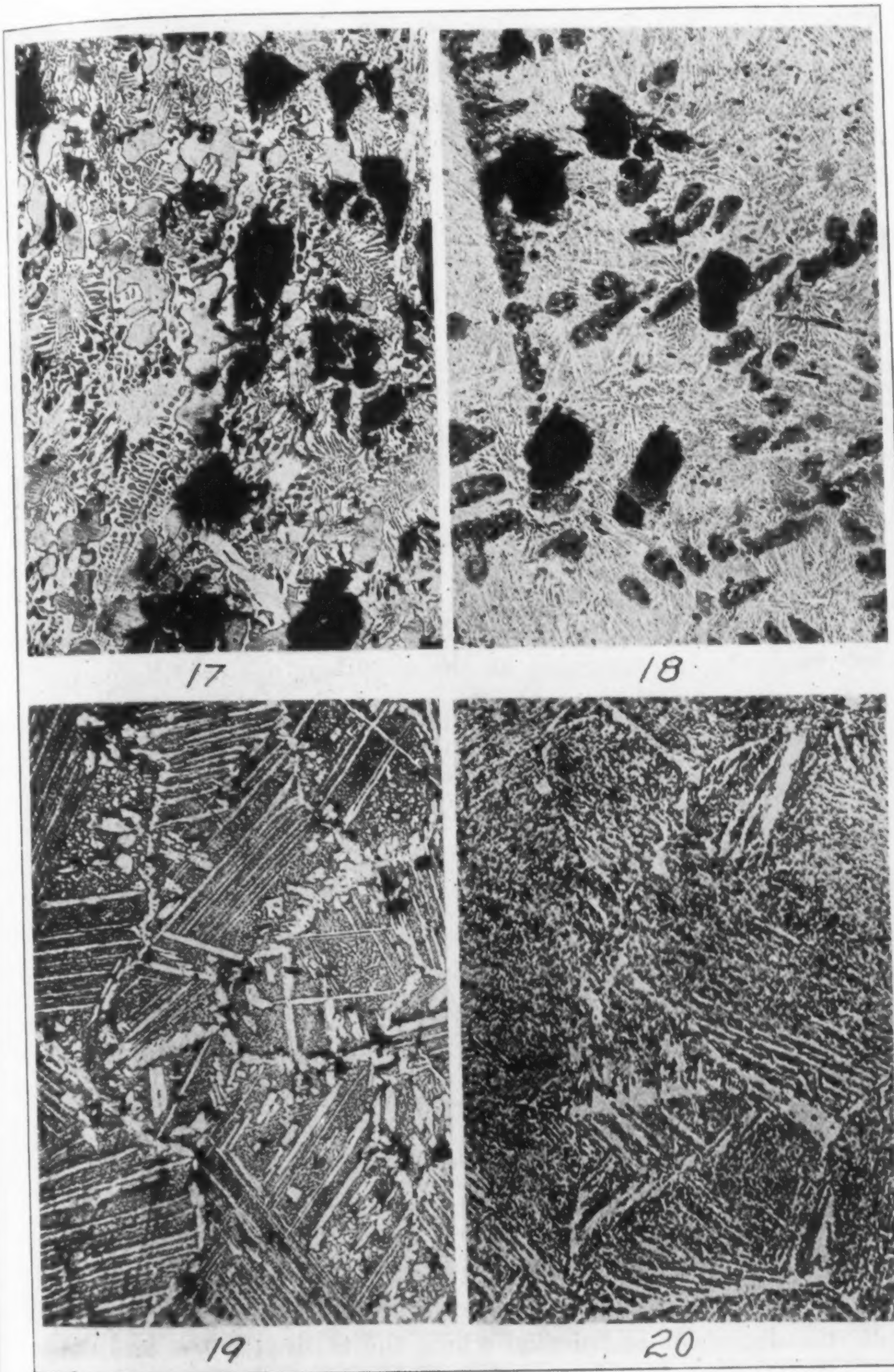

Fig. 17—Austenite Dendrites in Eutectic Matrix. Specimen is Severely Pitted. Cranbourne Meteorite. 50x. Fig. 18—Large Pits Appear in Dendrite Cores. Cranbourne Meteorite. 50x. Fig. 19—Widmanstatten Pattern in a 50 Per Cent Nickel Oxide, 50 Per Cent Iron Oxide Fusion. 50x. Etched in Boiling Hydrochloric Acid. Fig. 20—Widmanstatten Pattern Developed by Intercleavage Expulsion of Ferrite, in a Heat Treated, Nickel Steel. All Specimens Etched in 2 Per Cent Nitric Acid in Alcohol, Except Fig. 19.

The probable position of the carbon in these specimens has been mentioned above and illustrated in Fig. 10, as well as in the description of the Cranbourne specimen.

As mentioned above, the severe pitting of the Cranbourne and Mt. Joy specimen may have been caused by the escape of volatile matter; or to the decomposition by weathering or solution of such constituents as the lawrencite ($FeCl_2$) with which earlier reports credit the Mt. Joy specimen. The compound lawrencite was not observed in the inspection of an unetched section of the Cranbourne specimen and would not be expected to appear unless special precautions for its preservation were taken in the preparation of the specimen to avoid dissolving this constituent.

DISCUSSION OF MICROSTRUCTURAL FEATURES

Plessite Eutectoid and Tænite Divorce

Assuming that the eutectoid plessite is composed of tænite and kamacite, the position of the eutectoid range still remains to be determined. Guertler's[9] diagram placed the maximum at approximately 23 per cent nickel; while Pfann's[10] diagram, based upon metallographic work, confines the same point to 18 per cent nickel. Additional work will be necessary to prove the position of the eutectoid point. The structurally irregular forms in which the eutectoid occurs, make the metallographic method of research less decisive.

The general statement made from macroscopic observations that the eutectoid plessite fills the meshes between kamacite bands may be misleading, due to details which the macrostructure does not clearly reveal. Forms in which the former eutectoid zones appear suggest that a complete divorce of its constituents, tænite and kamacite, may be developed. Several forms in which the "plessite" appears in this series of specimens are referred to in earlier passages. Obviously the composition of a receding eutectoid in any of these several forms would vary between the kamacite and tænite limits of the nickel-iron-meteorite diagram, depending upon the degree of completion which the tænite divorce and coalescence had reached.

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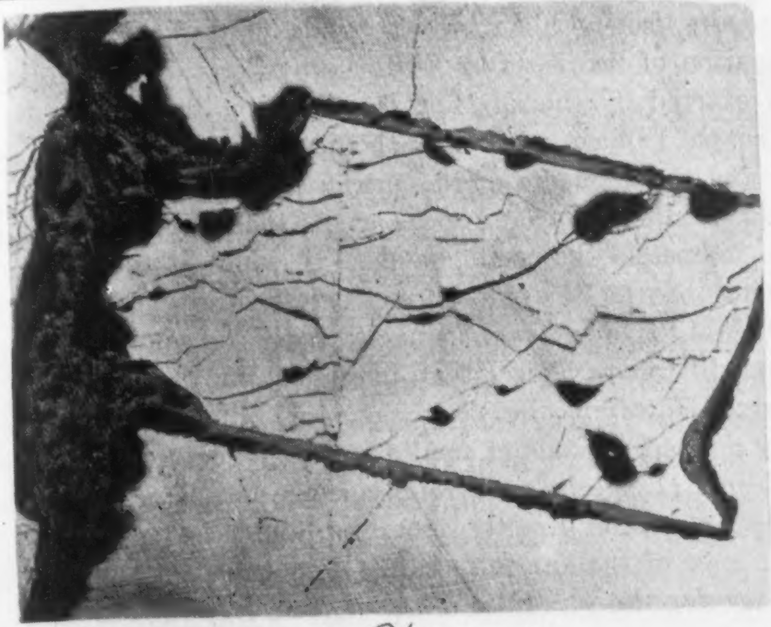
[9] Ibid.

[10] Metallographie, 1912, p. 163, Vol. I. Part I, Borntraeger, Berlin.



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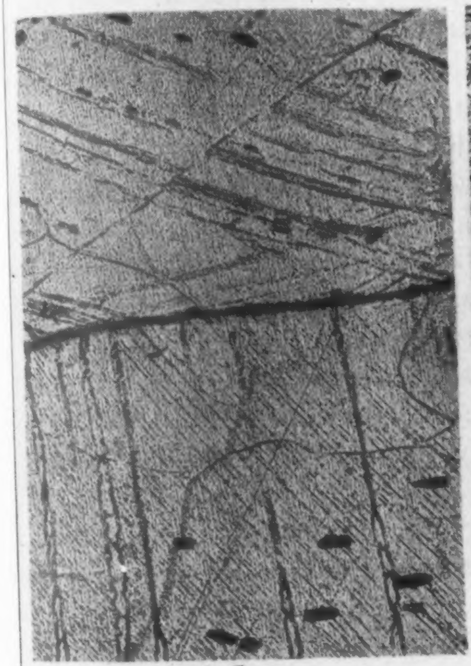

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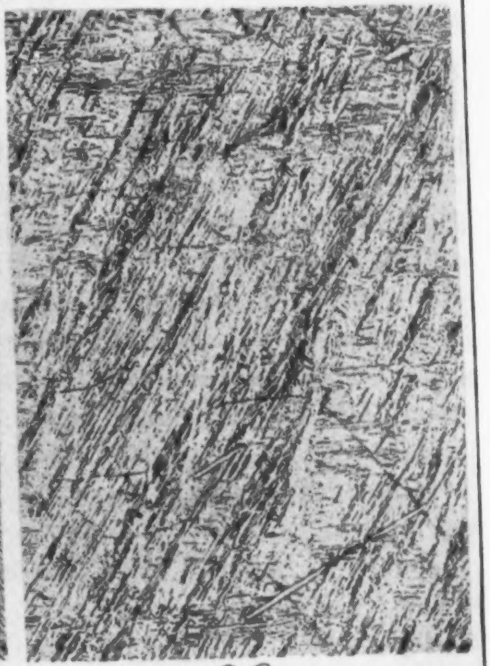

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Fig. 21—Angular Patch of Tænite, Enveloped in Oxide. Mt. Joy Meteorite. 50x. Fig. 22—Casas Grandes Meteorite Deeply Etched to Develop Neumann Lines within a Matrix Already Traversed by Neumann Bands in Widmanstatten Bands. 100x. Fig. 23—Deeper Etching Develops Faint Outlines of Grains which Suggests an Initially Granular Aggregation. Matrix is Heavily Streaked with Very Fine Lines, which may be Neumann's. St. Francois Meteorite. 50x. All Specimens Etched in 2 Per Cent Nitric Acid in Alcohol.

Guertler,[11] dealing more specifically with the occurrence of the tænite fringe about thick bands of kamacite, ascribed the segregation of tænite (Das Einformungs-Prozess) to the attractive force exerted by the kamacite bands upon the plessite eutectoid. The coarse kamacite bands or bodies were supposed to grow by absorbing the kamacite of the eutectoid, leaving the tænite residue to collect into pools or appear as littoral fringes about thin residual, eutectoid, kamacite bands. In view of the hypoeutectoid character of the low nickel meteorites, this explanation of the withdrawal of the solvent kamacite from the solute, tænite, might appear to be more logical than one ascribing the effect to a tænite divorce. However, the occurrence of independent particles of clearly defined crystals of tænite in the noneutectoid meteorites of the Group II specimens strongly suggests the precipitation and divorce of tænite directly from an under-cooled solid solution. The absence of the kamacite bands demonstrates that they are not necessary for the separation.

The various modifications of structure in which the divorced tænite appears might be expected to result from changes in the cooling rate during precipitation and coalescence. Osmond and Cartaud[12] have pointed out that the thick bands of kamacite were aligned in the octahedral pattern of gamma iron. This corresponds to the initial structure of the nickel-iron solid solution. Upon cooling, the gamma to alpha inversion occurs below 400 degrees Cent. (752 degrees Fahr.) at a temperature at which the solution is relatively immobile. For this reason the imprint of the coarse, gamma-iron structure is retained; cooling continues until the gamma to alpha inversion is reached and the tænite excess which is foreign to the new crystalline organization is expelled. The appearance, jointly, of eutectoid plessite with the tænite-edged bands of kamacite must have required a very long sojourn at and below the eutectoid temperature for its accomplishment. At the eutectoid temperature some eutectoid had formed where the position of the precipitate in the viscid solution was favorable. During the very slow cooling, the super-saturated nickel-iron solution managed to precipitate the tænite excess along the edges of the kamacite bands. The contacts between the kamacite bands which are distinctly visible in the macrostructure were too widely separated for the expelled tænite to negotiate, and the inter-band precipitation resulted.

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[11] Metallographie, 1912, p. 163, Vol. I. Part I, Borntraeger, Berlin.

[12] *Transactions* American Institute of Mining Engineers, Vol. 37, 1906, p. 842.

A more prolonged sojourn below the eutectoid temperature must have been necessary to effect the dismemberment of a previously formed eutectoid or the coalescence of bands or pools of tænite. The structures illustrating the tænite coalescence are common to the Group I meteorites.

The absence of coarse Widmanstatten bands in the Group II specimens would indicate a relatively rapid cooling through the primary crystallization, gamma-iron, range. The more rapid cooling would defeat the formation of thick octahedral bands and give rise to the thin, needlelike, intercleavage films which, as the St. Francois specimen shows, are arranged in a martensitic pattern. In this matrix, precipitation and divorce of tænite is more closely analogous to the precipitation and divorce of cementite from hypoeutectoid steels. The distribution, size, and well developed shape of the tænite particles suggest a long sojourn below the eutectoid temperature, subsequent to the relatively rapid cooling which prevented the growth of the banded octahedral pattern and also the formation of the normal eutectoid organization. The matrix in which the tænite rhombs are embedded must have reached equilibrium or remained in a hyper equilibrium state with respect to the precipitation of tænite. The appearance of tænite particles in meteorites analyzing less than 6 per cent nickel would require a leftward movement of the boundary of the kamacite (III) field of Guertler's diagram. However, the inhomogeneity of meteorite structures introduces difficulties in accurately determining the composition by ordinary sampling and the analysis of the local mass represented by the microscopically examined field, would probably be necessary to confirm this observation.

Widmanstatten and Neumann Bands

W bands and N bands and lines were first discovered in meteorites and subsequently reported in the structure of alloys and metals. The meteorites of Groups I and II show one or both of these markings. W bands were originally designated as the broad, octahedrically aligned kamacite bands that traversed the matrix of a meteorite. The tænite edge may or may not have been present. The application of the same term to similar structures in metallic alloys led to a disregard for the magnitude and orientation requirement. Belaiew[13] studied this effect in steel and other alloys and called all parallel intersecting, intercleavage, expulsions, Widmanstatten structures. Subsequent work[14] confined the designation once more to octahedral sections.

The macrographs of Figs. 2 and 3 show the coarse W bands in meteorites while Figs. 19 and 20 show the same pattern made of very much thinner bands of intercleavage expulsion origin. In a homogeneous solid solution, such as the martensites of ordinary steels, the intercleavage expulsion of the alpha iron phase along the cleavages of the gamma iron lattice would develop the triangular pattern which is another manifestation of the Widmanstatten structure. Figs. 15 and 16 show distinctly the triangular pattern which W bands have made in the matrix of the St. Francois meteorite. The rhombic particles of tænite appear to be unaffected by the several paths which the W bands prefer. The fineness of the tænite precipitation and the distinctly triangular sweep of many thin W bands suggested that an appreciable amount of nickel, remaining in solution in the St. Francois specimen, assisted in preserving the martensitic or octahedral pattern. W bands may be produced in a homogeneous matrix, as is evident in the case of the Dalton meteorite, a portion of which is shown in Fig. 2. Here the microstructure confirms the macroscopic appearance and reveals large areas composed of kamacite bands without the tænite film between them. For steels or alloys containing two or more components the current explanation for the occurrence of the Widmanstatten structure seems satisfactory: namely, that a precipitation of the solute occurs along the grain boundaries and cleavage planes of the crystalline framework of the solvent. When the pattern is developed in a pure metal or solid solution, a phase change would seem to be necessary to produce the intercleavage expulsions. When the pattern is developed in a pure metal or solid solution without the expulsion of an intercleavage phase then the octahedral alignment, usually developed during the granulation and growth of the octahedral grains, provides the proper pattern for the designation, "Widmanstatten."

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[13] *Journal* Institute of Metals, 1914, Vol. XII, No. 2, p. 46.

[14] *Journal* Institute of Metals, 1923, preprint.

It appears doubtful that a sharp distinction between Neumann and Widmanstatten bands has been carefully drawn. It is the lack of a definition for coarse N bands and fine W bands that makes a distinction between these two structural markings difficult particularly when both occur together in a solid solution type of matrix. A fundamental distinction between Widmanstatten and Neumann bands on the basis of the syngenetic and post genetic origin of the two might be made, without considering the different crystallographic alignment of the two markings. W bands may be defined as the coarse homogeneous bands, or the intercleavage expulsions of solute which accompany slow transformation or solidification. Neumann bands are the markings produced by a sudden deformation or shock below recrystallization temperatures.

Neumann bands have been reproduced in iron or steel by subjecting the metal to sudden impact at such rates of the application of deformation as accompany the impact test or an explosion.[15] The presence of N bands in meteorites has been ascribed similarly to impact; presumably with the earth upon termination of flight.

Neumann Bands

The classification of meteorites into octahedral or hexahedral groups, depending upon whether a Widmanstatten or Neumann band pattern appeared, is in many cases only correct insofar as the prominence of the Widmanstatten bands in the macrostructure is permitted to determine the crystal form. Osmond and Cartaud[16] have pointed out that the alpha iron formed upon recrystallization in low nickel-irons, below 400 degrees Cent. (752 degrees Fahr.), is crystallized on the gamma iron axes. The Widmanstatten bands, arranged in the characteristic octahedral pattern, are preserved below the temperature of transformation and the alpha iron which is then formed becomes a pseudomorph of the pre-existing gamma iron. In view of the above, there is no reason why N bands should not occur in irons classed as octahedral, which are sufficiently low in nickel and have been cooled at a slow enough rate to permit the gamma to alpha iron inversion en route. The resulting product would consist of alpha iron, in which N bands could be expected.

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[15] Foley and Howell. Neumann bands as evidence of action of explosives upon metal. *Transactions* American Institute Mining and Metallurgical Engineers, Vol. 68, 1923, p. 891.

[16] Ibid.

An excellent example of the occurrence of N bands in an iron classed as octahedral, appears on the Casas Grandes meteorite. Fig. 22 shows the junction between two coarse W bands. Each W band is traversed by one or more systems of N bands which change directions in each. The W band occupying the lower half of Fig. 22 is traversed by a second system of fine N bands that sweep diagonally across the figure in addition to the coarse N bands that run nearly vertically through the figure.

N bands are faintly visible in the matrix of Fig. 6, and more distinctly in Figs. 7 and 8. In Fig. 7 they sweep across the area in straight lines quite regardless of the network of grain like markings which are woven through the matrix. In Fig. 8, however, the N bands in the fine grained area assume a rough parallelism, although their individual courses change from grain to grain. There is the possibility that a parallel orientation in the coarse grained area and a confused orientation in the fine grained area is responsible for the changes in direction through the grains. A number of other factors may be responsible for the same features, since the bands, as shown in Fig. 8, are members of two, directionally distinct, systems.

Fig. 13 illustrates the occurrence of broad N bands, in the hexahedral, Mt. Joy specimen. The bands pass into a colony of tænite particles without obstruction or interference to their course. Where the N bands come in contact with larger bodies of tænite like those shown in Fig. 9, the bands disappear at the contact but reappear, in correct alignment, on the opposite side of the tænite body. The presence of the tænite either in large bodies or in minute particles does not appear to disturb the straight-line course which N bands usually adopt.

Fig. 23 reveals a subdued grain structure within a matrix swept by fine, parallel lines which resemble N lines because of their fineness and continuity. The martensitic texture of the matrix makes the lines difficult to resolve and nearly absorbs them in its angular pattern.

Can Neumann Bands Form in Gamma (Octahedral) Iron?

The composition and rate of cooling in all of the specimens described above, is such that alpha iron predominates in the final product. Alpha iron is built on the body-centered cubic lattice and exhibits a preference for the hexahedral form. Gamma iron, on the other hand, prefers an octahedral form and X-ray analyses have assigned to it the face-centered cubic form as a fundamental lattice unit. It is improbable that N bands would be found following an octahedral (W band) pattern in the meteorites of such low nickel content as those above because the temperature of the transformation of gamma to alpha iron lies below the temperature of stability of octahedral N bands. Assuming that such bands may occur, they would, no doubt, be erased in the recrystallization. Rapid cooling would assist the preservation of gamma iron, but N bands would, doubtless, be obscured in the resulting martensitic pattern.

It seems possible that N bands could appear in meteorites with a nickel or alloy content sufficiently high to prevent the gamma to alpha inversion, notwithstanding an extremely slow cooling. In such specimens the alignment of the N bands would be expected to follow the cleavages and conform to an octahedral (Widmanstatten or martensitic) pattern. In view of the fact that gamma iron twins readily upon deformation and N bands are mechanical twins, it is still doubtful whether an applied deformation would produce a twinned gamma iron or an octahedral pattern of N bands.[17]

SUMMARY

1. An investigation of six meteorites which were selected from a large collection because of available information regarding their metal and gas content was undertaken for the purpose of examining their microstructural features and correlating these with their composition and with certain facts known to physical metallurgy. In view of the similarity in composition of all except one of the meteorites, the corresponding specimens were conveniently placed into three groups, in which Groups I and II were similar in composition but differed in the form in which the nickel-rich, solute, tænite was precipitated from the low nickel, solvent, kamacite. Kamacite and tænite in nickel-iron meteorites form a eutectoid called plessite over the range of 6 to 28 per cent nickel. A separation of the meteorites of similar composition was

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[17] Some work on the production of N bands in gamma iron is contemplated at the Rolla, Mo. Station of the U. S. Bureau of Mines—F. B. Foley, Private Communication (Oct. 22, 1923).

made based on the form in which the excess constituent, tænite appeared.

Group I consisted of specimens in which the tænite of the eutectoid, plessite, appeared in various degrees of divorce. Features traceable to an original eutectoid pattern were observable.

Group II, similar in composition to Group I, is non-eutectoid and the precipitated tænite excess adopted distinctly rhombohedral forms in separating from the solution.

Group III consisted of a single, high-carbon iron which possessed a structure closely resembling hypoeutectic, cast iron.

2. A test for the presence of impurities such as oxides, carbides, sulphides, phosphides and nitrides was made and their distribution determined. Oxides appear in three important forms:

First; as the usual surface coatings and fissure fillings;

Second; as envelopes about tænite inclusions embedded within the Group III specimens;

Third; in pools, replacing the austenite cores near the surface of the single, high carbon specimen.

Small spots of sulphide were found in the Mt. Joy and St. Francois specimen.

Tests for phosphorus failed to prove its presence in discernible segregations. The presence of carbon in divorced tænite is described.

The iron chloride reported present in the Mt. Joy specimen was not observed, nor was evidence of nitrogen located. The Mt. Joy and Cranbourne specimens, which were selected because of a high gas content, were severely pitted; a condition which may have been brought about by the evolution of dissolved gas. Nitrogen, if present in the Cranbourne specimen, would have been obscured in the unexpected, high-carbon structure.

3. In view of the similarity in composition of Group I and Group II meteorites, one outstanding feature permitting a division, occurred in the degree of divorce of the tænite from the tænite-kamacite eutectoid, plessite. The difference in the mode of occurrence of the excess constituent, tænite, suggested that the factors active during the formation of Group II structures were not the same as those active for specimens of Group I. The modifications of an earlier eutectoid pattern in which the existing plessite occurs in the Group I specimens and the presence of distinct rhombs of

tænite in a non-eutectoid matrix of the Group II specimens, suggests that a direct precipitation and coalescence, or a precipitation and divorce, or a direct precipitation of tænite is possible in the tænite saturated matrix, when the precipitation is favored by a low, sub-eutectoid temperature and a very long sojourn. Coalescence suggests a long sojourn at approximately eutectoid temperature, while a divorce suggests a long sojourn below eutectoid temperature. Independent particles of tænite suggest a direct precipitation from a solid solution that had been comparatively rapidly cooled through the eutectoid temperature and very slowly, thereafter.

4. The true origin of the eutectoid range for plessite could not be estimated from these specimens due to the varieties in form from partial to complete divorce which the eutectoid, plessite, possessed.

The occurrence of free tænite in meteorites analyzing as low as 4.80 per cent nickel would demand a corresponding shift from 7 to less than 5 per cent in the solubility line for nickel in kamacite.

5. The mineralogical classification of metallic meteorites based on coarse macrostructural features is unsatisfactory, due to the loss of details which the macrostructure does not clearly reveal. Such details resulting from phase changes that take place in the fundamental crystal lattice during cooling are developed in the microstructure. A classification of meteorites based upon their macroscopic features which had largely been determined by their probable crystal-habit and the crystal habit in turn confirmed by the presence of Neumann or Widmanstatten bands, would be in error in view of the gamma to alpha iron change in irons of this composition and the accompanying change in habit from octahedral to hexahedral. The macrostructural features are in consequence, pseudomorph patterns of the actual structure. A physico-chemical basis of classification is urged with crystal form a factor subordinate to composition.

6. The Widmanstatten structure forms in an octahedral crystal. When the structure is developed in a pure metal or solid solution without the expulsion of an inter-band phase then the octahedral alignment usually developed during the earlier granulation and growth of the octahedral grains provides the proper

pattern for the designation, Widmanstatten. Therefore, in meteorites Widmanstatten structure may form whether or not a phase change or an intercleavage precipitation of tænite occurs. In the absence of a phase change, the W pattern in the low-nickel iron is built during the birth and growth of the large gamma iron grains which are octahedral in form and face-centered cubic in lattice. With a phase change, the new precipitate expelled along the cleavages is more stable and, therefore, resistant to etching, or in the higher-nickel irons, the W outline is accentuated by the nickel-rich, tænite precipitated along the octahedral cleavages of the gamma iron prevalent during the precipitation. When finally cold, the octahedral pseudomorph in either case largely consists of the body-centered, hexahedral, alpha iron.

7. The fallacy of classifying meteorites into octahedral or hexahedral groups, depending upon whether Widmanstatten or Neumann bands occur, is mentioned. It appears doubtful that a sharp distinction between Neumann and Widmanstatten bands has been carefully drawn. Gamma iron N bands developed by deformation would be interpreted as W bands on account of their octahedral alignment. Widmanstatten and Neumann bands are structural features which are developed in distinctly different temperature ranges. The fact that each may form independently of the other is emphasized and hypothetical as well as actual illustrations are taken to show that the directional courses which the bands may assume are dependent upon the crystal structure predominating at the interval of their formation.

THE CHEMISTRY OF IRON AND STEEL

By F. T. Sisco

Abstract

In the manufacture of iron and plain carbon steels, five principal chemical elements enter. These are, carbon, manganese, silicon, sulphur, and phosphorus. The first three are of benefit to the metal either because of valuable properties they confer upon the material or because of their power of scavenging or purification. The last two, sulphur and phosphorus, are considered very harmful and, consequently, are kept, as far as possible, to a minimum. The metals used in the manufacture of alloy steels are nickel, chromium, vanadium, tungsten, molybdenum, and sometimes copper, cobalt, uranium, and zirconium. Occasionally silicon and manganese in amounts exceeding the usual percentages are used as alloys. Alloy steels containing nickel, chromium, vanadium, tungsten, silicon, and manganese are of great value. Molybdenum and copper are used in steels with special uses. The value of uranium, cobalt, and zirconium as alloys in steel is doubtful.

Introduction

THE manufacture of iron and steel is essentially a chemical process. From the blast furnace, through the various conversion processes to the finished product, all of the manufacturing operations are based principally upon the science of chemistry; the three great chemical processes, oxidation, reduction and combustion, entering into practically every operation.

The chemistry of iron and steel is not a simple science; on the contrary, it is one attended by many difficulties, chief among which is the fact that most of the reactions take place at high temperatures (between 2000 and 3200 degrees Fahr.), and that many of the reactions are completed in closed chambers where observation of conditions is difficult, if not impossible. Again, many of the chemical reactions occurring in the various melting and refining operations are reversible and require that conditions be closely controlled so that they will proceed to completion in the manner desired.

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Although some of the reactions occurring in the various steps of the different processes are not thoroughly understood, most of them have been worked out by the tedious method of trial and can now be stated with a good deal of assurance.

In the manufacture of iron and plain carbon steels, which form the great bulk of the steel industry, five chemical elements enter prominently. They are carbon, manganese, silicon, sulphur and phosphorus. In alloy steels we have in addition to these five: nickel, chromium, vanadium, tungsten, molybdenum and occasionally copper, cobalt, uranium and zirconium.

Of the five common elements, carbon, manganese and silicon are of great value either because of the distinctive properties they confer upon the metal or because of their scavenging power, while sulphur and phosphorus are considered extremely harmful. Consequently, the iron and steel maker is confronted with the task of controlling the amount of carbon, manganese and silicon, and keeping sulphur and phosphorus to a minimum.

Sulphur and phosphorus are introduced into iron and steel with the raw materials; carbon, manganese and silicon may be wholly or partially introduced with the raw materials or may be added at some step in the processing. The alloying elements, nickel, chromium, vanadium, tungsten and the others, are nearly always added at some step in the process.

In discussing the chemistry of iron and steel it is necessary that we first of all consider the five elements usually found in all iron and steel products—carbon, manganese, silicon, sulphur and phosphorus—taking up the manner in which they exist in the metal, how they are introduced into the metal, and how they may be controlled or reduced to a minimum. With that completed we can then pass on to the discussion of the alloying elements.

The manufacture of iron and plain carbon steel is a relatively old process, hence the characteristics of the five common elements, their mode of occurrence, introduction or reduction to a minimum are fairly well understood. The alloy steels, on the contrary, are comparatively new in ferrous metallurgy; in the main they were mostly evolved by the method of trial and in many cases the alloying element, in the light of its occurrence, introduction, and control, is still imperfectly understood.

Another factor, and a most important one too in the chemistry of iron and steel, and one which often has great influence on the properties of the metal, is the foreign matter introduced into the metal at various stages in the melting and refining. Under the head of foreign matter come nonmetallic inclusions—"dirt" is a more expressive word—and gas. Solid nonmetallic inclusions and gas may be the reaction-products of the oxidation or reduction of any or several of the five or more elements occurring in the metal or they may be introduced from extraneous sources; from the refractory lining, from the slag, or from the hot gases used in melting and refining.

Thus we see that the chemistry of iron and steel involves four possible factors:

1. Control of the precentage of carbon, manganese and silicon;
2. Reduction of sulphur and phosphorus to a minimum;
3. Special properties conferred on the metal by the addition of one or more alloying elements; and
4. Preventing the introduction of solid nonmetallic inclusions and gas, or at least reducing them to a minimum.

OCCURRENCE, IMPORTANCE AND RELATION OF THE COMMON ELEMENTS IN IRON AND STEEL

Before taking up the chemical reactions involved in the various processes in the manufacture of iron and steel, we will look for a moment at the five common elements in the metal and will discuss their occurrence, importance and their relation to each other.

Carbon

Carbon is the most important element in plain carbon steel. Until the introduction of alloy steels the control of the carbon content was the factor of greatest importance in the manufacture of steel products. This was due to the possibility of securing, with proper treatment, a wide range of physical properties by proper control of the carbon content.

Carbon occurs in iron and steel as the element or as a compound. As the element, it occurs in iron as graphite, which may take several forms, depending upon the process of manufacture. As a compound, it occurs in iron and steel as iron carbide, Fe_3C, and as a compound of manganese and carbon, Mn_3C, or with some other element, such as chromium, vanadium, tungsten, etc.

Iron carbide, Fe_3C, has the property of existing in several physical states. It may exist by itself, it may become associated with pure iron to form an aggregate known as pearlite, it may exist in large masses, or may, on the contrary, become so thoroughly emulsified and dispersed that it is not recognizable under a high power microscope. In its various states of dispersion or concentration the carbon as iron carbide is the main factor in the formation of the various microscopic constituents found in steel. These range from a solid solution of iron carbide in gamma iron, known as austenite, to martensite, troostite, sorbite, granular- or emulsified-pearlite and true or laminated-pearlite, in which it occurs as plates of iron-carbide, alternating with free ferrite.

Each of these constituents has distinct physical properties which are largely the result of the relative dispersion or condition of the carbon. It is because of this property of existence in a number of distinct phases or the property of changing its condition or physical state as the result of thermal treatment, that steel may be hardened, tempered or annealed. It is because of the wide diversity of physical properties resulting from physical changes in the condition of the iron carbide that steel has become the master metal, and that carbon is considered its most important element. Even in the alloy steels, carbon remains the most important element because the benefit conferred by many of the alloying elements is due to the formation of carbides of these metals.

Carbon is introduced into iron from the coke or fuel that is used to reduce the iron ore in the blast furnace. It may be present up to 4.50 per cent. This quantity may all occur as combined as iron carbide, Fe_3C; it may be practically all elementary carbon, graphite; or it may be varying percentages of both.

In the useful steels the amount of carbon ranges from 0.02 to 1.50 per cent. In general it occurs as iron carbide or as the carbide of one of the other elements present; manganese, chromium, vanadium, tungsten, etc. With drastic methods of treatment the carbon may be present in the elementary state as temper carbon, a finely dispersed form of the element analogous to graphite. This condition of the carbon is exceptional.

Carbon is easily oxidized and eliminated from molten iron and steel. Also it may easily be introduced into the molten metal. Most important, the oxidation or introduction may be closely controlled. Carbon may be oxidized to some extent when the metal is far below its melting point; at 1300 to 2200 degrees Fahr. the surface of the steel becomes decarburized if an excess of oxygen is present. Carbon may be introduced into solid steel. Under suitable conditions it will penetrate $\frac{1}{16}$ inch or more into the metal at temperatures between 1500 and 2000 degrees Fahr. This is case carburization.

Carbon is eliminated from molten steel by means of an oxide such as ferrous oxide, FeO, or manganese oxide, MnO. The carbon has a greater affinity for the oxygen of the metallic oxide than the metal and thus forms carbon monoxide, which escapes from the bath as a gas.

Carbon is introduced into molten metal as coke, coal, charcoal or other carbonaceous material or as some metallic alloy high in carbon, such as pig iron, washed metal, ferromanganese, ferrochromium, etc. Carbon in the form of coke, coal or such, if introduced into a molten bath of iron, is greedily dissolved, and becomes completely distributed throughout the metal.

Manganese

Next to carbon, manganese is the most important element in iron or plain carbon steel. The element performs two functions; it confers characteristic properties on the metal and is very active in deoxidizing and degasifying it. This last property, all in all, is the most valuable. Manganese oxide is a constituent of some iron ores and, consequently, from 0.10 to 2.00 per cent or even more is introduced into the metal in the smelting of these ores in the blast furnace. As the manganese occurring in iron is often lost by oxidation in some later refining process, it is necessary that it be added to the melt at a later stage of the process. A convenient method of adding the element to steel is through the medium of manganese-rich iron alloys. These alloys are ferromanganese containing 80 per cent manganese and 10 per cent iron, and spiegeleisen containing 20 per cent manganese and 75 per cent iron. Both of these ferro-alloys are smelted from manganese ores with coke in the blast furnace and contain between 4 and 7 per cent carbon, less than 2.00 per cent silicon and up to 0.40 per cent phosphorus. Sulphur is not present in appreciable amounts.

Manganese has a great affinity for sulphur, so when iron and steel is molten, theoretically all of the sulphur combines with the manganese to form manganese sulphide, MnS, provided sufficient manganese is present. One part of sulphur requires, theoretically, 1.7 parts of manganese to form 2.7 parts of manganese sulphide. Practically, however, a much greater excess of manganese is necessary; the ratio is about 1 to 4. Manganese sulphide is insoluble in iron and steel, both molten and solid. It forms, therefore, in the finished product, a solid nonmetallic inclusion and usually can be detected with the microscope as rounded dove-gray areas in the transverse section or as elongated areas in the longitudinal section.

Manganese sulphide in normal amounts (sulphur, 0.040 per cent or below) does not segregate to a harmful degree. This is due to its high melting point, which is near that of molten steel, as well as to the fact that it disperses easily. Consequently it does not tend to collect in masses of appreciable size during solidification of the metal. When high sulphur percentages are present in steel (0.060 per cent and above), and occasionally with moderate amounts, it becomes more difficult to keep all of the sulphur as manganese sulphide. Due to mass action some iron sulphide is formed which dissolves in the manganese sulphide, and lowers the melting point, thus promoting segregation.

After the sulphur is satisfied, the balance of the manganese present in iron and steel combines with the carbon to form manganese carbide, Mn_3C. In this form it acts similarly to iron carbide. Manganese carbide, in the amounts found in normal steels, cannot be detected with the microscope.

The amount of manganese in plain carbon steels varies from almost nil to 2.00 per cent. Above this higher limit and up to about 9.00 per cent manganese apparently causes brittleness. A special alloy steel having quite remarkable properties contains between 11 and 14 per cent manganese and about 1.25 per cent carbon. This steel, the discovery of Sir Robert Hadfield, has come into extended use where great hardness and toughness is desired.

Silicon

Silicon occurs in iron in percentages ranging from 0.50 or less up to 4.00 per cent or more. It is introduced into the blast furnace as silica, SiO_2, in the gangue or earthy matter in the ore, in the ash of the coke, and in the limestone. This is reduced by carbon at high temperatures and is dissolved by the iron. Most of this silicon is lost by oxidation in later melting processes.

Silicon is valuable to steel principally for its deoxidizing and degasifying effect. It is one of the most efficient degasifying agents known and so is used in some grades of steel for the prevention of blowholes. It is added to plain carbon and alloy steels as a ferro-alloy containing approximately 50 per cent silicon and 50 per cent iron, or in some cases as an alloy containing 10 to 15 per cent silicon and 85 to 90 per cent iron. As silicon is used chiefly as a scavenger, the percentage of the residual element left in the metal is small. In some mild steels where no ferrosilicon is added, only a trace will be found. In high grade alloy and tool steels that must be very sound, up to 0.35 or 0.40 per cent may be present. Higher percentages of silicon (1 to 5 per cent) are used in some alloy steels.

Silicon combines with the iron as iron silicide, $FeSi$ (Fe_2Si?), and as such dissolves in the ferrite (pure iron), with which it forms a solid solution. Silicon cannot be detected with the microscope and in the amount present in normal steels (0.01 to 0.40 per cent) has no appreciable effect on the physical properties. A few authorities have stated that percentages between 0.30 and 0.50 produce some brittleness.

Sulphur

Sulphur is an undesirable impurity in both iron and steel. Much effort and money are continually expended to keep the percentage of this element at a minimum. Sulphur cannot be consistently reduced to a minimum under oxidizing conditions or at all by an acid slag, consequently it is not removed in the Bessemer process, the acid open hearth or acid electric process and only partially and inconsistently in the basic open hearth process. The element may be controlled in the blast furnace but only when conditions for its removal are completely met. The basic electric furnace process removes the element almost completely under normal operating conditions.

Sulphur is introduced into the blast furnace with the coke in which it occurs as a sulphide. It is sometimes present in small amounts in the ore and limestone. By proper furnace operation most of the sulphur can be removed in the slag. The quantity left remains until the metal reaches the basic open hearth furnace where one-fourth to one-third more may be removed. This removal in the basic open hearth furnace is partly offset by the fact that the furnace gases in this process often contain sulphur which may be absorbed by the steel. The basic electric process is the only one that removes the element completely and consistently.

The quantity of sulphur in iron ranges from 0.015 to 0.150 per cent. In first class irons for steel making, an effort is made to keep the sulphur below 0.050 per cent. In normal steels the quantity is usually below 0.040 per cent and nearly always below 0.060 per cent. A high sulphur content confers upon the steel the property of easy machinability. Steels containing up to 0.130 per cent are made for use as bolts, screws and allied materials.

As noted in a previous paragraph, if sufficient manganese is present all of the sulphur should be in the form of manganese sulphide. If this is not the case, the sulphur combines with the iron to form iron sulphide, FeS. This constituent forms a eutectic with iron which melts at a temperature far below that of molten steel and so tends to segregate in those portions of the metal last to solidify. The harmful effects of iron sulphide are apparent in hot working the metal. At rolling or forging temperatures the iron sulphide eutectic is liquid, thus destroying the cohesion of the crystal masses. The metal may thus be sufficiently weakened to crack or even break into pieces in the rolls or under the hammer. When this occurs the steel is "hot short."

The danger from sulphur in steel comes, therefore, from two sources. In the first case if insufficient manganese is present to combine with all of the sulphur, this latter element forms iron sulphide, which causes hot shortness. Even if the steel rolls or forges satisfactorily, the iron sulphide eutectic has formed a network around the grains, destroying their cohesion and greatly weakening the metal. In the second case when too much sulphur is present (0.060 per cent or above) even with a sufficient excess of manganese to combine with all of it, there is likely to be some iron sulphide formed which dissolves in the manganese sulphide and lowers the solidification point of this constituent sufficiently so that it segregates appreciably. These segregated areas will be loci of weakness where fracture may start under repeated stresses.

Recent investigation on the effects of sulphur in steel have shown that in normal amounts (0.060 per cent or below) and with a sufficient excess of manganese present, there are probably few or no bad effects due to this element.

Phosphorus

Phosphorus occurs in all iron ores as a phosphate. All of the phosphates in the ore and the small amount in the limestone and coke are reduced in the blast furnace to phosphorus, which go into the iron as Fe_3P. Phosphorus may be reduced to a minimum by an oxidation process and basic slag, as in the basic open hearth and basic electric furnace. It is unaffected by acid slags, consequently there is no removal of this element in the Bessemer process, acid open hearth or acid electric furnace.

After melting, iron contains all of the phosphorus present in the furnace burden, and it may range from 0.020 to 0.800 per cent or even more, depending upon the ore, coke and limestone used. In the northern part of the United States pig iron for steel making is graded according to the phosphorus content; Bessemer iron contains less than 0.100 per cent and basic iron from 0.150 to 0.400 per cent.

When only a small quantity of carbon is present, as in steel, the iron phosphide is held in solid solution by the iron. In the case of irons high in carbon and containing a considerable phosphorus content, most of the iron phosphide is thrown out of solution and forms a ternary eutectic of iron phosphide, Fe_3P, iron carbide, Fe_3C, and iron, Fe. The approximate composition of this eutectic is 91 per cent iron, 7 per cent phosphorus and 2 per cent carbon. This eutectic assumes characteristic forms, as seen by the microscope, and can be readily recognized. By suitable etching or heat-tinting the three constituents of the euctectic may be identified. The melting point of this eutectic is about 1850 degrees

Fahr. In high phosphorus irons (0.50 to 1.00 per cent) sufficient of the eutectic is present to influence the solidification point of the iron. High phosphorus iron is more fluid at the usual casting temperature than low phosphorus iron, hence about 0.50 to 0.80 per cent is often desirable when thin and intricate castings are poured.

Aside from the one advantage of conferring fluidity, phosphorus is considered harmful to iron. It is claimed that it produces brittleness, although this assumption has recently been contradicted. It may be safely said, however, that iron with a high phosphorus content is not able to withstand shock as well as iron in which the element is lower. This is due to the hardness of the phosphide eutectic. Phosphorus is considered as a harmful impurity in steel, consequently in irons to be used for steel making, the percentage of the element is kept as low as economically possible.

In steels the percentage of phosphorus rarely exceeds 0.130 per cent. This amount is only present in steels made by the Bessemer process. In acid open hearth and acid electric steel the percentage ranges from 0.030 to 0.060 and in basic open hearth and basic electric steel it is almost always low, usually below 0.040 per cent and often below 0.030 per cent. As has been mentioned, the small amount present in steel is held as iron phosphide, Fe_3P, in solid solution in the ferrite. As is characteristic with constituents in solid solution it cannot be detected by the microscope, although suitable etching reagents will reveal the presence of the element when segregated.

Phosphorus is commonly assumed to cause brittleness or "cold shortness" in steel. In amounts exceeding 0.10 per cent it probably tends to enlarge the grains, a factor in promoting brittleness. Even when present in normal amounts (0.040 per cent and below), it has been accused of causing ghosts, banded structure and segregation of the ferrite, especially in nickel steels. Its role in this respect is questionable, in the light of recent research. As an impurity, however, phosphorus has an unsavory reputation, gained over a period of many years, so the steel maker makes every effort to keep the amount of the element as low as possible. In basic melting processes it causes no concern, as it is quickly and cheaply removed from the metal. In acid processes, on the contrary, it can be controlled only by controlling the analysis of the scrap and pig iron used as a base for the steel.

OCCURRENCE AND RELATION OF ALLOYING ELEMENTS

The metals used as alloys in steel are nickel, chromium, vanadium, tungsten, molybdenum and sometimes cobalt, uranium and zirconium. In addition silicon and manganese, in amounts exceeding the usual percentages in plain carbon steel, are sometimes used as alloys.

It will not be possible to take up in detail the effect of the various alloying elements on the physical properties of steel, either alone or in combination. This is a vast subject. We will, therefore, confine our discussion to the mode of occurrence of these elements after being alloyed with the steel, the chemical compounds they form, and, briefly, the influence of these compounds or elements on the general character of the metal.

It has already been mentioned that most of the alloy steels have been discovered by the method of trial. This was necessary as it has long been known that a large percentage of some metals may have a totally different effect on steel than a small percentage. Consequently the pioneers in alloy steel had to experiment until they secured the results they desired. As a result, while the effect of an alloy or combination of alloys on the physical properties may be well known, the cause for the change in properties can, in many cases, only be surmised.

Nickel

Nickel is added to steel as the pure metal containing about 99 per cent nickel. It dissolves in all proportions when added to molten steel, and remains in solution when the metal is solid. Nickel apparently does not oxidize in a bath of molten steel, consequently it is impossible to remove the element after it is once in the metal. Nickel has the power of depressing the transformation points 20 to 40 degrees Fahr. for each one per cent present below that of carbon steel of the same carbon content. The useful nickel steels contain between 3 and 5 per cent of the element.

As nickel is held in solid solution it cannot be detected with the microscope. Although it is universally claimed that nickel is held in solid solution, there are several structural defects characteristic of nickel steels and found practically alone in this grade of material, that seem to raise the question as to whether or not the solid solution is the only state in which nickel occurs. Among these defects are the well known "flakes." Others characteristic of nickel steel include banded structure, and segregated ferrite. It is probable that eventually it will be found that nickel exists in some form other than a solid solution.

The addition of about 3 per cent nickel to steel increases the ultimate strength appreciably, with only a slight decrease in ductility. One of its greatest advantages is the higher yield point (elastic limit?), which is often increased as much as 50 per cent.

Nickel has the property of apparently increasing the amount of pearlite. A 0.30 per cent carbon steel containing 3.50 per cent nickel, when examined by the microscope, is practically all pearlite in the annealed condition. Much less free ferrite is evident than would be the case with a 0.30 per cent plain carbon steel.

One of the noteworthy advantages of nickel steels is their ability to resist shocks and repeated stresses. In this respect they are much superior to carbon steel. Nickel steels should always be used in the heat treated condition.

Chromium

Chromium is added to steel as a ferro-alloy containing about 70 per cent chromium and varying percentages of carbon. The alloy used most frequently contains 6 to 8 per cent carbon. Small amounts of silicon, manganese, sulphur and phosphorus are found in most commercial alloys. The amount of chromium added to steel varies from 0.50 to 2.00 per cent. A special high chromium steel containing about 13 per cent chromium is known as "stainless steel." In high speed steels about 4.50 per cent chromium is present.

Chromium as an alloying metal is used principally as a hardening element. It must, however, be accompanied by carbon. When chromium is added to molten steel it combines with the carbon to form double carbides of iron and chromium, of unknown or uncertain composition. The formula for these carbides may be expressed as x Fe_3C y Cr_3C_2. The desirable physical properties of chromium and chromium-nickel steels are obtained by heat treatment. With the proper heat treatment, steel containing chromium, and especially those containing chromium and nickel, combine intense hardness with high strength and high yield point. They are also well able to withstand sudden and repeated shocks.

Chromium oxidizes easily in a bath of molten metal. Chromium and chromium-nickel steels are difficult to manufacture because they seem especially liable to surface and internal defects.

Vanadium

When added to steel in small amounts, part of the vanadium dissolves in the ferrite and part combines with carbon to form double carbides of iron and vanadium of the approximate formula x Fe_3C y V_4C_3. In the amount found in carbon-vanadium and chromium-vanadium steels,—about 0.20 per cent,—probably very little of the element is in the form of carbides, most of it has gone into solution in the ferrite.

The effect of small amounts of vanadium (0.15 to 0.25 per cent) on the physical properties of steel is quite remarkable. This amount of vanadium increases the ultimate strength and yield point as much as 50 per cent with no sacrifice of ductility. These steels also show exceptional resistance to impact, vibration and reversal of stress. They are always used in the heat treated condition. The best combination of physical properties results from the addition of about 1.00 per cent chromium and 0.15 to 0.25 per cent vanadium to a steel containing 0.30 to 0.60 per cent carbon.

Vanadium is added to high speed steel, in amounts ranging from 1.00 to 2.00 per cent. Its exact effect upon this grade of material is not exactly known, except that it apparently acts as an intensifier to the tungsten and chromium. It is certain that high speed steels containing vanadium have superior cutting ability over those containing none of the element. In the comparatively large amount in high speed steel, vanadium probably exists principally as the carbide.

Vanadium is added to steel as the ferro-alloy containing about 35 per cent vanadium. Other elements, in appreciable amounts, are absent. Vanadium oxidizes very easily; in fact it is one of the most difficult elements to keep in the metal. The results of its intense deoxidizing power are not especially evident as vanadium and chromium-vanadium steels often contain numerous seams and oxidation defects. It has been claimed that vanadium is a very efficient degasifier, being particularly effective in removing nitrogen. This, however, is only an assumption.

It is quite certain that vanadium has a great influence on the grain size of the metal. Vanadium and chromium-vanadium steels are uniformly fine grained when compared with other steels of about the same composition and treatment. It is well known that grain size influences the physical properties to a remarkable degree, so the exceptional physical results obtainable in vanadium and chromium-vanadium steels may be due, in part at least, to the effect of the element on the grain size.

Tungsten

Tungsten is a remarkable alloying element in that when present in steel in large amounts (10 to 20 per cent) it confers the property of great hardness at high temperatures. This condition, which is known as "red hardness," is one in which the tool is as hard or harder at high temperatures (up to 800 degrees Fahr. or more) than at normal temperatures.

Tungsten is added to steel as the iron-tungsten alloy containing 60 to 80 per cent tungsten and the balance iron, or as the powder containing in excess of 90 per cent pure tungsten. Other elements are present in such small amounts that they may be neglected. Tungsten readily oxidizes in a bath of molten metal but may be easily reduced from its oxide by means of carbon. Due to its high melting point and high specific gravity it is sometimes difficult to alloy tungsten powder with molten steel. Ferrotungsten alloys somewhat easier, although care must be used even with this material.

Tungsten forms a series of compounds with iron and carbon. These carbides and tungstides when associated with chromium and vanadium carbide are responsible for the property of red hardness. From recent researches it is probable that when high speed steel containing 18 per cent tungsten and about 5 per cent chromium is slowly cooled from 1650 to 1700 degrees Fahr. the tungsten is in the form of iron tungstide, Fe_2W, partially dissolved in the iron and partially free, and in the form of tungsten carbide, WC. The chromium is present as free carbide, probably Cr_4C. Vanadium if present is also in the form of a carbide. When heated to a high temperature for hardening these carbides go into solution in the austenite. In the hardened state, most of the carbides of chromium, vanadium and tungsten and part of the iron tungstide are probably in solid solution in the austenite.

It is thought that these complex carbides of tungsten, chromium and vanadium, form a solid phase similar in its properties to a eutectic, apparently melting at a lower temperature than the steel itself. When the steel solidifies in the ingot these carbides tend to segregate, giving the metal a coarse, weak, fibrous structure. Heat treatment will not affect the solution of these segregated carbides. They can, however, be broken up by careful hot working. Because of the possibility of the presence of these segregated carbides, high speed steel must receive a most careful treatment in forging.

In low percentages (below 10 per cent) tungsten forms the carbide, WC, robbing some of the iron carbide of its carbon. The steel then contains a mixture of iron carbide, Fe_3C, and tungsten carbide, WC. As the percentage of tungsten approaches 10, practically all of the carbon is in the form of tungsten carbide. Above 10 per cent the tungsten in excess of that necessary to combine with the carbon reacts with iron to form iron tungstide, Fe_2W.

The most useful steels containing tungsten are the high speed grades with 10 to 20 per cent of the element, together with 4 to 5 per cent chromium and usually 1 or 2 per cent vanadium; and the tungsten magnet steels containing about 5 per cent tungsten. All tungsten steels are used in the heat treated condition.

Molybdenum

Molybdenum is added to steel as ferromolybdenum (70 to 80 per cent molybdenum), and (50 to 60 per cent molybdenum), as molybdenum powder (95 per cent molybdenum), or as calcium molybdate. In any of these forms no trouble is experienced in alloying the metal with steel. Although molybdenum oxidizes with ease, the oxide is relatively unstable at high temperatures and is, consequently, readily reduced. Almost perfect absorption is obtained even with calcium molybdate; this salt breaking up into calcium oxide and molybdic acid, which in turn is reduced to molybdenum.

The amount of molybdenum added to steel is generally between 0.20 and 1.00 per cent. A number of years ago molybdenum in large percentages was tried as a substitute for tungsten to obtain high speed properties. By experiment it was found that molybdenum was two to three times as efficient as tungsten but the addition of a large amount (2.00 per cent or more) gave trouble in hot working. When heated for forging the molybdenum apparently volitilized from the surface of the ingot or billet, resulting in a section that was not uniform. In addition, in large percentages, the element was evidently not distributed uniformly in the steel.

More recently molybdenum in amounts up to 1.00 per cent either alone or combined with chromium, nickel or both, has been found to produce superior physical properties. In the usual amounts (0.50 per cent or less) molybdenum dissolves in the ferrite. In large percentages (2.00 per cent or more) it partly dissolves in the ferrite and partly forms complex carbides of iron and chromium. The formula, Fe_3Mo_3C has been assigned to the iron-molybdenum carbide.

The most characteristic effect of molybdenum in steel is its ability to prevent the rapid dissociation of martensite and thus to retard the formation of troostite and sorbite.

In general molybdenum steels need a higher drawing temperature than similar steels with no molybdenum. Molybdenum increases the temperature range in which the steel may be successfully hardened. It also has the property of making steels weld as satisfactorily or more so than carbon steels.

Molybdenum affects the physical properties in much the same way as nickel. With the same carbon content the same physical properties can be secured from a steel containing 1.00 per cent chromium and 0.25 to 0.35 per cent molybdenum, as from a steel containing 1.00 per cent chromium and 3.00 per cent nickel.

Cobalt

Cobalt is occasionally added to high speed steel. The amount used is about 3.50 per cent. It is doubtful if cobalt has any appreciable effect on the physical properties or general characteristics and quality of steel. A special valve steel containing about 1.25 per cent carbon, 13.00 per cent chromium and 3.50 per cent cobalt is on the market. It is claimed that cobalt intensifies the effect of chromium in resisting oxidation at high temperatures. No direct proof has been given of this intensifying effect.

In adding cobalt to steel the pure metal is used. Like nickel it dissolves readily in the molten bath. Cobalt probably forms a solid solution in the iron, although it has been stated that the stable carbide, Co_3C, is also formed.

There is little or no direct evidence that cobalt is of any benefit to steel in any amount.

Copper

Copper has long been considered a harmful impurity. It was thought that copper made steel hot short. This hot shortness has never been evident when the metal contained a normal amount of manganese. Only when practically no manganese was present does copper cause steel to be hot short and then only in a certain temperature range (about 1800 to 2000 degrees Fahr.). It is likely that the hot shortness caused by copper is from the formation of copper sulphide or copper oxide, which constituents could not exist if sufficient manganese were present.

In small amounts—0.20 to 0.30 per cent—copper increases the resistance of steel to corrosion. This increased resistance to corrosion is of such value that a large tonnage of copper bearing steels is made each year and used for roofing, wire and other products exposed to the atmosphere.

A few experiments have been made on steels containing 0.50 to 1.00 per cent copper. Preliminary results on these steels indicate that copper is of benefit to the metal. In fact it is probable that should occasion arise, chromium-molybdenum or copper-molybdenum steels could be substituted for nickel or chromium-nickel steels without sacrificing any of the valuable properties of the latter.

In alloying copper with steel the pure metal is used. It dissolves readily and will persist in the steel even when the metal is held under an oxidizing slag.

Silicon

There are two general classes of steels in which silicon is used as an alloying element. In the first, the high silicon steels, from 3.00 to 4.50 per cent silicon is present. These steels have high magnetic permeability and high electrical resistance and are extensively used in electrical machinery. The other class, the silico-manganese spring steels, contain 1.25 to 3.00 per cent silicon and 0.50 to 0.80 per cent manganese. They are strong and have a higher deflection under load than carbon steels. They are used when a material that is cheaper than chromium-vanadium steel is desired. Both grades of silicon steels are used in the heat treated condition.

Silicon exists in steel as iron silicide, FeSi (Fe_2Si?). When present in large amounts (2.50 to 4.50 per cent) and when considerable carbon is present, the iron silicide becomes associated with iron carbide (cementite) Fe_3C, to form double carbides. These carbides are relatively unstable, tending to break up into iron silicide and elementary carbon. In annealing high silicon steels graphitic carbon is often formed. We will discuss this property of silicon in promoting the precipitation of graphite in a latter section.

Silicon in high percentages (about 4.00 per cent) is thought to cause brittleness.

For large percentages, silicon is added as the ferro-alloy containing 50 per cent silicon and 50 per cent iron. It oxidizes readily, and unless added to a deoxidized bath as in the electric process, it must be added to the ladle.

Manganese

There is only one grade of steel that contains manganese as an alloy. This is high manganese steel containing 10 to 14 per cent manganese and 1.00 to 1.30 per cent carbon. As cast or rolled these steels are austenitic at atmospheric temperature and contain free carbides, making them very hard, brittle and weak. By quenching in water from a bright red heat the manganese is held as a single phase solid solution in the austenite. The steel then becomes very hard, strong and tough. As is characteristic with austenitic steels, manganese steel has a low elastic ratio.

High manganese steel is usually made by the basic open hearth process. This applies to ingot production, as most of the castings made from this material are produced by the electric process. In the open hearth process, scrap and pig iron are melted and practically all of the carbon, manganese and phosphorus oxidized and removed. The heat is tapped and mixed with molten ferromanganese brought to the open hearth direct from the blast furnace or from a cupola. After mixing, the metal is teemed into molds. In the electric process, manganese steel scrap may be melted without loss of manganese. Manganese steel melts at about 2400 degrees Fahr., which is near the melting point of pig iron. Another characteristic of this material is that it has much less of a mushy range than ordinary carbon steels.

Uranium

Uranium has been used as an alloying element in high speed steel but it is of doubtful benefit. In this respect uranium is similar to cobalt. Many extravagant claims have been made for both uranium and cobalt high speed steel but little, if any, proof has been forthcoming to uphold these claims.

Uranium appears to enter into solid solution in the iron and is claimed to make the pearlite more fine grained. It is not known whether uranium forms carbides or not but probably some are formed when considerable (above 1.00 per cent) of the element is present. Some metallurgists have claimed that uranium forms complex carbides in high speed steel that increase secondary hardness; and that uranium increases the hardening power and lowers the transformation point.

Uranium is added to steel as the ferro-alloy containing about 60 per cent of the element. Uranium is a powerful deoxidizer and is alloyed with steel with great difficulty. The best results have been obtained by adding it to the ladle.

Zirconium

Zirconium is an element about which very little is known. It is procurable as a ferro-alloy but not without large amounts of some other elements, notably silicon, nickel or titanium. The metal is a powerful deoxidizer and is alloyed with great difficulty.

The large amount of silicon, nickel or other elements present has made it difficult, in investigating the physical properties, to determine whether any beneficial results would be due to the zirconium, the other elements or to one intensifying the effect of the other. The persistent rumor that Germany was using zirconium steels as light armor plate led the Bureau of Mines and others to undertake experiments in alloying the metal with steel. So far no results have been obtained that showed any promise. A recent investigation (A. L. Field, A. I. M. M. E., Feb., 1924) showed that zirconium forms sulphides, probably of the composition ZrS_2, and that it acts similarly to manganese in preventing hot shortness. Considerable research work must be done on the effect of zirconium in steel before any definite statements either one way or the other can be made.

SUMMARY

In summing up we may say that nickel, chromium, vanadium and molybdenum are of great benefit as alloying elements in steel. They each produce characteristic and superior properties either alone or in combination with each other. Tungsten, of course, is of inestimable value for high speed steels. Manganese and silicon produce alloy steels of value for specific uses. Copper may be included in this class. The advantages of cobalt, uranium and zirconium are questionable; perhaps further investigation may evolve steels of great value containing one or more of these three elements. It may be said again that alloy steels are practically in their infancy. They have been mostly discovered by the method of trial and in numerous cases, although the effect of the element on steel is well known, the cause is still more or less shrouded in mystery. However, alloy steels have made possible the present development of our automotive and aircraft industries.

(To Be Continued in March TRANSACTIONS*)*

ENDURANCE PROPERTIES OF ALLOYS OF NICKEL AND OF COPPER—PART II

By D. J. McAdam, Jr.

Abstract

This paper presents results of an investigation at the U. S. Naval Engineering Experiment Station. The investigation includes nickel, monel metal, constantan, cupro-nickel, several ternary alloys of nickel, copper, alpha bronze, alpha brass, aluminum bronze, Muntz metal, Naval brass and manganese bronze.*

In continuation of the general investigation described in Part I, the paper describes an investigation of the effect of severe cold working on the endurance properties of nickel, and of moderate cold working on the endurance properties of several alloys.

By means of the information thus obtained, the endurance limits of a number of alloys in the annealed condition are then calculated from the endurance limits of the alloys as rolled or drawn. These endurance limits are utilized in graphs to illustrate the influence of chemical composition on endurance properties.

Scope of Investigation

In Part I of this paper[1] results were presented of endurance tests on many alloys of nickel and of copper. Endurance limits were estimated and the relationships of endurance limits to tensile, torsional and shearing strength were discussed. A tentative discussion was given of the influence of chemical composition on endurance properties. The discussion was, necessarily, tentative because at that time definite allowance could not be made for the influence of cold working on the physical properties of these alloys.

In order to make definite allowance for the influence of plastic deformation it would be desirable to have a series of endurance-test results for the alloys in the fully annealed condition as well as after various degrees of plastic deformation. To obtain this information for such a large series of alloys, the total number of individual endurance tests required would be very great. It seems probable, however, that if the influence of cold working on the endurance properties of a few alloys be determined, this information can be used to make allowance for the influence of cold working on the endurance properties of any alloy. A preliminary investigation has now been made of the influence of cold working on the endurance properties of a few alloys. On the basis of the results of this investigation, the influence of cold working on the endurance properties has been estimated and the endurance limit in the fully annealed condition has been calculated for each of the other alloys listed in Part I. With these calculated endurance limits, and the few experimentally determined endurance limits of the fully annealed alloys, graphs have been drawn to represent the influence of chemical composition on the alloys of nickel and of copper.

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*This paper is published by permission of the Secretary of the Navy.

[1] Part I of this paper was published in the January, 1925, issue of Transactions, Vol. VII, page 54.

A paper presented before the Boston Convention of the Society, September, 1924. The author, D. J. McAdam, Jr., is metallurgist with the U. S. Naval Engineering Experiment Station, Annapolis, Maryland.

INFLUENCE OF SEVERE COLD WORKING ON THE ENDURANCE PROPERTIES OF NICKEL

The nickel, material A, used in this investigation, had the chemical composition listed in Table I. This material and the two "German silvers" listed in Table I were furnished by the International Nickel Company. The nickel was in bars $1\frac{1}{4}$ by $1\frac{7}{16}$ inches in cross-section. It had been cold-rolled to produce a tensile strength of about 165,000 pounds per square inch and had been annealed by the manufacturers at 550 degrees Fahr.

This material as received, and after annealing at various temperatures, was tested to determine its tensile and endurance properties. The temperatures and other details of the annealing are given in Table II. The material designation for the nickel, after annealing at any temperature, consists of the letter A and the annealing temperature divided by 100. Thus the material designations in Table II, for the nickel annealed at various temperatures from 550 to 1600 degrees Fahr., range from A-5.5 to A-16. Tension tests of the nickel were made after each of the annealing treatments listed in Table II. The results are given in Table III, and graphs illustrating the influence of annealing temperature on tensile properties are shown in Fig. 2.

Table I
Chemical Composition
All Values in Per Cent

Material	Material Desig-nation	C	Ni	Cu	Zn	Fe	Mn	Si	S
Nickel, Cold-Rolled	A	0.25	98.95	0.12	....	0.50	0.10	.06	.175
‡Copper-Nickel-Zinc Alloy, Cold-Drawn	CH	...	17.63	65.3	17.15	0.23	...	..	...
‡Copper-Nickel-Zinc Alloy, Cold-Drawn	CG	...	10.89	60.08	29.05	0.20	...	..	...

Table II
Annealing Treatment

Material	Material Desig-nation	Heated to — Deg. Fahr.	Time Held Min.	Cooled in
Nickel, Cold-Rolled	A-5.5	550	60	Furnace
Nickel, Cold-Rolled	A-8.5	850	60	Furnace
Nickel, Cold-Rolled	A-9.5	950	60	Furnace
Nickel, Cold-Rolled	A-10.	1000	60	Furnace
Nickel, Cold-Rolled	A-10.5	1050	60	Air
Nickel, Cold-Rolled	A-11.	1100	60	Furnace
Nickel, Cold-Rolled	A-11.5	1150	60	Air
Nickel, Cold-Rolled	A-12.25	1225	60	Air
Nickel, Cold-Rolled	A-13.4	1340	60	Furnace
Nickel, Cold-Rolled	A-14.	1400	60	Furnace
Nickel, Cold-Rolled	A-16	1600	60	Furnace
Nickel, Hot-Rolled	AW-2	1400	60	Furnace
Monel Metal, Cold-Rolled.........	BK-1	1600	60	Furnace
Monel Metal, Cold-Rolled.........	BH-2	1600	60	Furnace
Monel Metal, Hot-Rolled	AA-1	1600	60	Furnace
Constantan, Hot-Rolled	CE-1	1450	60	Furnace
Copper-Nickel-Chromium Alloy, Forged	D-1	1500	60	Furnace
Copper-Nickel-Tin Alloy, Cold-Drawn	CF-1	1500	60	Furnace
Copper-Nickel-Zinc Alloy, Hot-Rolled	CD-1	1400	60	Furnace
Copper-Nickel Alloy, Cold-Rolled	B-1	1400	60	Furnace
‡Copper-Nickel-Zinc Alloy, Cold-Drawn	CH-1	1200	60	Furnace
‡Copper-Zinc-Nickel Alloy, Cold-Drawn	CG-1	1100	60	Furnace
Copper, Cold-Drawn	CL-1	1200	60	Furnace
Alpha Copper-Tin Alloy, Cold-Drawn	CK-1	1200	60	Furnace
Aluminum Bronze No. 1, Rolled..	BJ-1	1200	60	Furnace
Aluminum Bronze No. 2, Rolled..	BJa-1	1300	60	Furnace
Aluminum Bronze No. 3, Rolled..	BJb-1	1200	60	Air
Aluminum Bronze No. 4, Rolled..	BJc-1	1200	60	Furnace
Alpha-Copper-Zinc Alloy, Cold-Rolled	BP-1	1200	60	Furnace
Alpha-Copper-Zinc Alloy, Cold-Drawn	CJ-1	1200	60	Furnace
Naval Brass, Hot-Rolled	U-1	1200	60	Furnace
Manganese Bronze, Hot-Rolled ...	BG-1	1200	60	Furnace

‡German Silver.

Endurance tests by the rotating-cantilever method (Part I) were made with material as received and with material that had been annealed at 550, 850, 1100, 1400 and 1600 degrees Fahr. The type of specimen and the method of finishing are described in Part I. The type was "Finish 13," as described in Part I.

The results of the endurance tests are represented graphically on a semi-logarithmic scale in Fig. I. In the upper graph of Fig. I are shown the results obtained with nickel as received and with nickel that had been annealed at 550 and 850 degrees Fahr. To designate these three materials three kinds of marks are used as described in the legend for the upper graph of Fig. 1. As shown in this graph the endurance properties of the material as received, the material annealed at 550 degrees Fahr., and the material annealed at 850 degrees Fahr., are the same. The slope of the line representing average stress-cycle relationship is very steep from a stress of 70,000 pounds per square inch to a stress of about 45,000 pounds per square inch. From this point the slope decreases rapidly until the line becomes nearly horizontal at a stress of 40,000 or 41,000 pounds per square inch. This rapid decrease in slope below a stress of about 45,000 pounds per square inch is much more apparent in this graph than it would be in a graph drawn with less open vertical scale. This type of graph makes it possible to estimate the "endurance limit" very accurately.

As shown in Fig. 1, the graph for material A-11 is not so steep as the graph for materials A, A-5.5 and A-8.5. There is considerable variation in the endurance properties of different specimens of this material. The average stress-cycle relationship, however, is nearly as indicated by the broken line graph. The annealing at 1100 degrees Fahr. has evidently raised the endurance limit of material A-11 about 9000 pounds per square inch above that of the material as received. The tensile strength of material A-11, however, as shown in Table III, is about 12,000 pounds per square inch lower than that of material A. Not only has the form of the stress-cycle graph been changed but also the endurance ratio has been increased from 0.24 to 0.34 by the annealing at 1100 degrees Fahr. It is worthy of note that at slightly below this temperature the cold-worked material begins to recrystallize.

The lower two graphs of Fig. 1 show results obtained with material that had been annealed at 1400 and 1600 degrees Fahr.

Table III
Average Results in Static Tension Tests

Each Value is Average of Two Specimens Except as Indicated

Material	Material Designation	Heat Treatment	Tensile Strength, Lbs. Per Sq. In.	Johnson's Limit, Lbs. Per Sq. In.	Proof Stress, Lbs. Per Sq. In.	Elastic Limit, Lbs. Per Sq. In.	Proportional Limit, Lbs. Per Sq. In.	Elongation in 2 In., Per Cent	Reduction of Area, Per Cent
Nickel, Cold-Rolled	A	†As Received	**166,200	**108,600	**109,000	**58,300	**71,600	**12.2	**18.8
Nickel, Cold-Rolled	A-5.5	Annealed	165,500	112,000	103,500	20,000	69,000	14.0	21.9
Nickel, Cold-Rolled	A-8.5	Annealed	160,000	111,000	109,000	92,500	64,800	14.0	25.1
Nickel, Cold-Rolled	A-9.5	Annealed	150,300	98,000	96,500	80,000	81,500	17.8	25.8
Nickel, Cold-Rolled	A-10	Annealed	151,500	95,500	70,000	5,000	65,500	18.0	25.0
Nickel, Cold-Rolled	A-10.5	Annealed	144,400	87,000	71,500	30,000	*43,000	15.8	23.0
Nickel, Cold-Rolled	A-11	Annealed	**142,600	**86,300	**70,300	**18,300	**50,000	**16.3	**24.8
Nickel, Cold-Rolled	A-11.5	Annealed	106,400	+	30,000	9,000	+	13.3	18.8
Nickel, Cold-Rolled	A-12.25	Annealed	*81,000	+	*22,000	*10,000	+	*29.0	*42.5
Nickel, Cold-Rolled	A-13.4	Annealed	72,500	+	16,500	3,800	+	42.0	50.5
Nickel, Cold-Rolled	A-14	Annealed	73,400	+	17,800	5,000	+	42.8	49.8
Nickel, Cold-Rolled	A-16	Annealed	70,400	+	14,300	6,000	+	47.8	54.8
Nickel, Hot-Rolled	AW-2	Annealed	§76,200	§30,000	34,700	27,300	§25,100	§47.0	§69.0
Monel Metal, Cold-Rolled...........	BK-1	Annealed	77,100	+	21,300	15,000	+	48.0	64.3
Monel Metal, Cold-Rolled...........	BH-2	Annealed	84,400	+	26,300	*15,000	+	50.0	76.1
Monel Metal, Hot-Rolled............	AA-1	Annealed	77,300	+	30,000	22,500	+	48.0	73.0
Constantan, Hot-Rolled	CE-1	Annealed	70,300	27,500	26,500	19,000	14,000	48.8	79.3
Copper-Nickel-Chromium Alloy, Forged	D-1	Annealed	100,400	44,000	43,000	30,000	29,500	27.0	44.3
Copper-Nickel-Tin Alloy, Cold-Drawn.	CF-1	Annealed	57,800	+	16,300	6,800	+	*33.0	*51.5
Copper-Nickel-Zinc Alloy, Hot-Rolled.	CD-1	Annealed	51,100	+	12,300	6,500	+	47.3	72.7
Copper-Nickel Alloy, Cold-Rolled.....	B-1	Annealed	44,400	+	9,000	5,000	+	48.8	70.9
‡Copper-Nickel-Zinc Alloy, Cold-Drawn	CH	As Received	62,400	33,500	38,000	22,500	20,300	28.0	49.6
‡Copper-Nickel-Zinc Alloy, Cold-Drawn	CH-1	Annealed	54,600	17,000	18,000	10,500	16,500	49.5	61.5
‡Copper-Zinc-Nickel Alloy, Cold-Drawn	CG	As Received	58,700	28,500	31,500	22,500	12,500	49.5	59.0
‡Copper-Zinc-Nickel Alloy, Cold-Drawn	CG-1	Annealed	55,600	21,000	21,500	13,500	17,000	56.0	58.8
Copper, Cold-Drawn	CL-1	Annealed	31,500	+	4,200	2,000	+	56.8	75.8
Alpha Copper-Tin Alloy, Cold-Drawn.	CK-1	Annealed	48,800	+	14,300	5,000	+	64.0	79.5
Phosphor Bronze, Rolled............	F-1	Annealed	*42,400	*18,000	*15,000	*13,000	*8,000	*52.5	*70.5
Aluminum Bronze No. 1, Rolled.....	BJ-1	Annealed	57,800	14,500	14,500	3,800	10,000	76.5	72.0
Aluminum Bronze No. 2, Rolled.....	BJa-1	Annealed	*65,500	+	*20,000	*15,000	+	*74.5	*66.5
Aluminum Bronze No. 3, Rolled.....	BJb-1	Annealed	62,300	+	21,800	5,000	+	24.3	23.0
Aluminum Bronze No. 4, Rolled.....	BJc-1	Annealed	89,000	+	39,800	3,800	+	37.3	42.6
Alpha Copper-Zinc Alloy, Cold-Rolled	BP-1	Annealed	44,600	+	9,300	4,500	+	73.5	76.8
Alpha Copper-Zinc Alloy, Cold-Drawn	CJ-1	Annealed	46,500	9,000	9,300	2,500	8,500	73.8	73.5
Muntz Metal, Hot-Rolled............	BF	As Received	**65,100	**31,200	*30,000	*25,000	**23,300	**37.0	**55.4
Muntz Metal, Hot-Rolled............	BF-8.4	Quenched in Iced Brine, D'n at 840°F.	**65,600	**26,000	27,400	22,000	**20,000	34.5	42.3
Muntz Metal, Hot-Rolled............	□	......	58,600	..	27,000	..	..	..	..
Naval Brass, Hot-Rolled............	U-1	Annealed	58,500	12,500	13,400	8,500	7,000	47.0	50.5
Manganese Bronze, Hot-Rolled.......	BG-1	Annealed	67,000	+	18,000	11,500	+	35.5	31.3

□No Material available. On similar material, however, annealed results were 10% lower than on the material as received. These values, therefore, are 90% of the respective values obtained with the BF-8.4 material. +Stress-strain graph curved from origin. *One determination only. **Average of three determinations. §Average of four determinations. †This material had been annealed by the manufacturer at 550 degrees Fahr. ‡German silver.

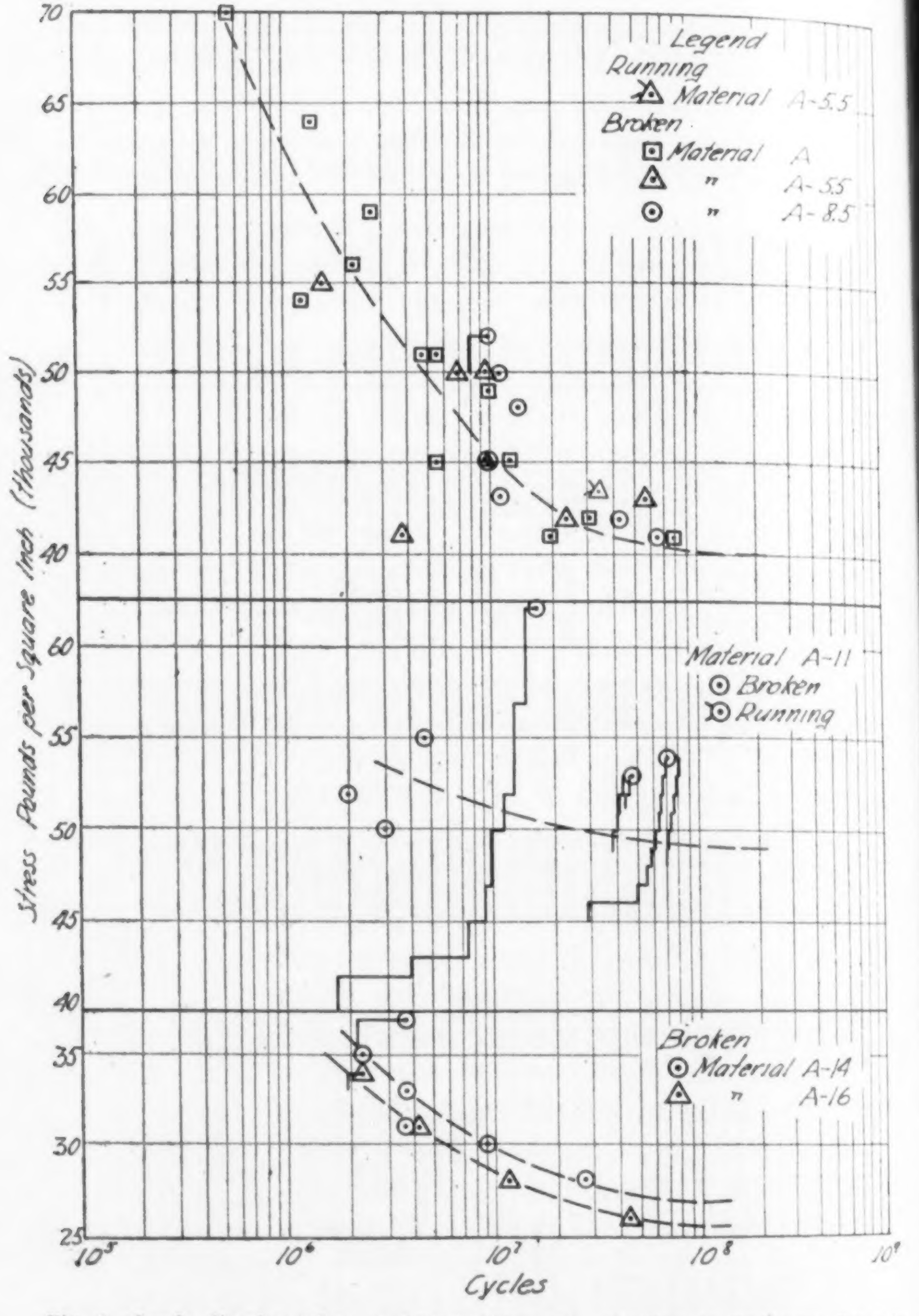

Fig. 1—Graphs Showing Effect of Cold Working and Annealing on Endurance Propertie of Nickel.

respectively. Although with these two materials few tests were made, the results when plotted show clearly the form of each stress-cycle graph and indicate definitely the "endurance limit."

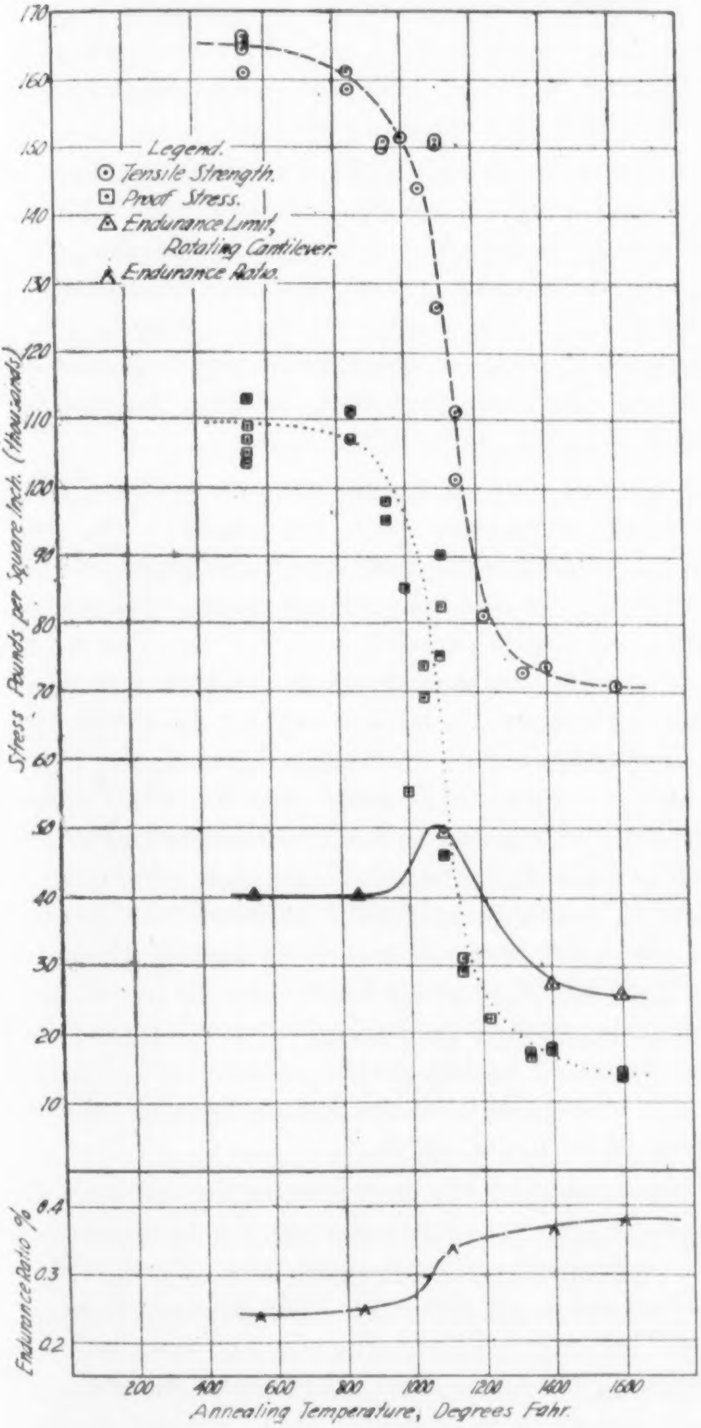

Fig 2—Graphs Showing Effect of Cold Working and Annealing on Endurance Properties of Nickel.

The form of the stress-cycle graph for the fully annealed material A-16 and for materials A-11 and A-14 is practically the same. The endurance ratios for materials A-14 and A-16 are only very little higher than that for material A-11.

The results illustrated in Fig. 1, therefore, show that a high degree of cold working greatly decreases the "endurance ratio." Annealing this cold-worked material at the temperature of incipient recrystallization, raises the endurance ratio until it is nearly equal to that of fully annealed material. The endurance limit of nickel at incipient recrystallization is higher, although the tensile strength is lower, than that of nickel that has been severely cold-worked and not recrystallized.

The influence of annealing temperature on the endurance properties, in comparison with its influence on other physical properties of cold-worked nickel, is illustrated in Fig. 2. The upper two graphs in this figure illustrate the influence of annealing temperature on tensile properties. The "proof stress," as defined in Part I, is the stress that causes permanent elongation of 0.0001 inches per inch length (0.01 per cent). As shown by the upper curve, which is typical of cold-worked metal, the tensile strength of the nickel begins to decrease rapidly with increase in the annealing temperature above about 850 degrees Fahr.; above about 1050 degrees Fahr. the slope of the graph is very steep. The curve of endurance limits is evidently horizontal at least up to 850 degrees Fahr. Between 850 and 1100 degrees Fahr. the ordinate increases from 40,000 to about 49,000 pounds per square inch; the most abrupt increase is probably between 950 and 1050 degrees Fahr., as illustrated by the graph. Above 1100 degrees Fahr. the curve of endurance limits slopes downward approximately parallel to the curve of tensile strength.

The lower curve of Fig. 2 illustrates the influence of annealing temperature on the "endurance ratio." As illustratred by this curve the endurance ratio increases from about 0.24 to 0.34 between the abscissas of 850 and 1100 degrees Fahr. Above an abscissa of 1100 degrees Fahr. the slope of the curve is slight and the curve gradually approaches a horizontal direction. The steepest part of this curve is evidently at an abscissa representing the temperature of incipient recrystallization, probably about 1050 degrees Fahr.

Figs. 1 and 2, therefore, show that increasing the tensile strength of nickel by severe cold working does not cause a proportional increase in the endurance limit. An increase of 137 per cent in the tensile strength by cold working caused an increase of only 57 per cent in the endurance ratio. In other words, severe cold working decreases the endurance ratio about one-third.

Experiments are now being made to determine the effect of lesser degrees of cold working on the endurance properties of nickel. Experiments on other alloys would seem to indicate that the effect of cold working in lowering the endurance ratio increases more than in proportion to the degree of cold working. For the alloys that have been tested, a moderate degree of cold working has little effect on the endurance ratio.

INFLUENCE OF MODERATE COLD WORKING ON THE ENDURANCE PROPERTIES OF MONEL METAL AND ALUMINUM BRONZE

Nearly all the endurance tests described in Part I were made with alloys as received. Many of these alloys had been cold-rolled or drawn. To estimate the degree of cold working that each of these alloys had received, tension tests have now been made with annealed specimens. The results are given in Table III along with some results of tension tests on material not listed in Part I. These results should be compared with the tension test results obtained with material "as received," as listed in Table II of Part I.

With a few of these annealed alloys endurance tests have been made so that it is now possible to compare the endurance properties of these alloys with the endurance properties (listed in Table IV of Part I) of the same alloys as rolled or drawn.

The upper graph of Fig. 3 shows results of rotating-cantilever endurance tests made with monel metal, material BK-1. Tests on this material in the cold-rolled condition, as described in Part I, showed that it had a tensile strength of 88,300 pounds per square inch and a rotating-cantilever endurance limit of 29,000 pounds per square inch. The endurance ratio was, therefore, about 0.33. In the annealed condition it has a tensile strength of 77,100 pounds per square inch. The enhancement of tensile strength by cold working was, therefore, only about 14 per cent.

As shown in Fig. 3, the endurance limit of the annealed monel metal is evidently about 26,000 pounds per square inch. The endurance ratio is, therefore, about 0.34 and is practically the same as that of the same material as cold-rolled. A moderate degree of cold working, therefore, has not appreciably decreased the endurance ratio of monel metal.

Another alloy, whose endurance properties in the "as rolled" condition were described in Part I, is aluminum bronze, material BJb. This alloy as rolled had a tensile strength of 83,400 pounds per square inch. The same alloy annealed has a tensile strength of 62,300 pounds per square inch. The enhancement of tensile strength by cold working was, therefore, only about one-third. Results of endurance tests on this alloy in the annealed condition are shown in Fig. 4. The endurance limit of the annealed alloy is evidently about 20,000 pounds per square inch, whereas the endurance limit of the alloy "as rolled" was 29,500 pounds per

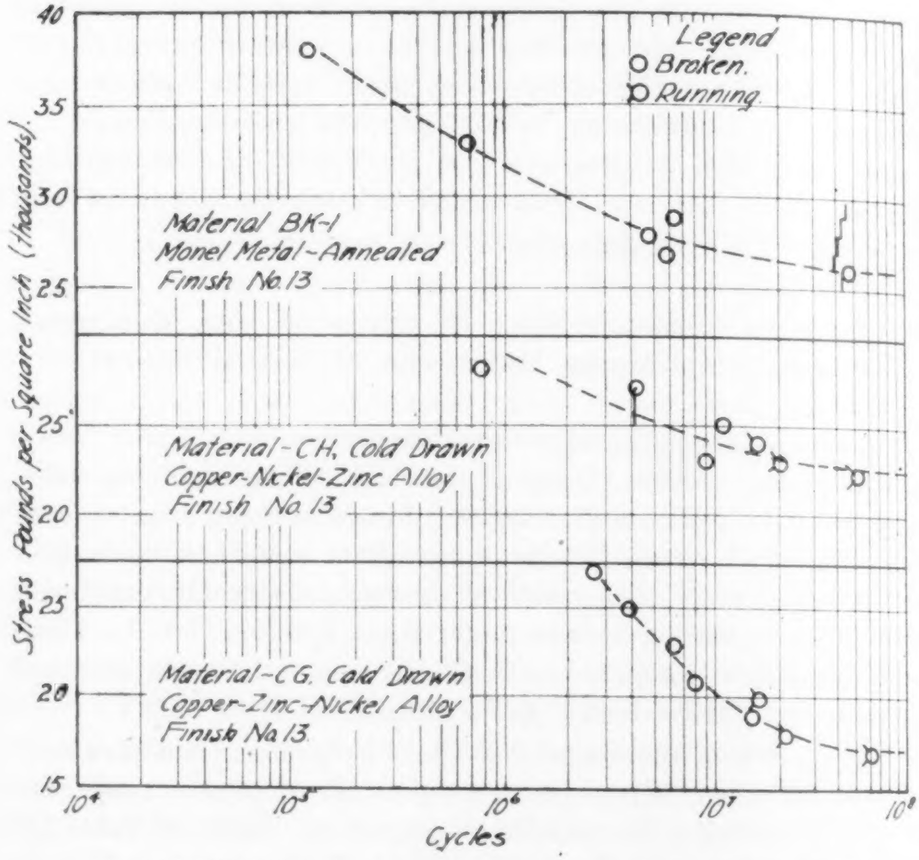

Fig. 3—Results of Rotating-Cantilever Tests of Monel Metal and German Silver.

square inch. The endurance ratios in the annealed and "as rolled" condition respectively are 0.35 and 0.32. Evidently, therefore, a moderate degree of cold working has not appreciably decreased the endurance ratio of aluminum bronze.

As listed in Table IV of Part I, the alternating torsion endurance limits of cold-rolled and hot-rolled copper are approximately proportional to the tensile strengths.

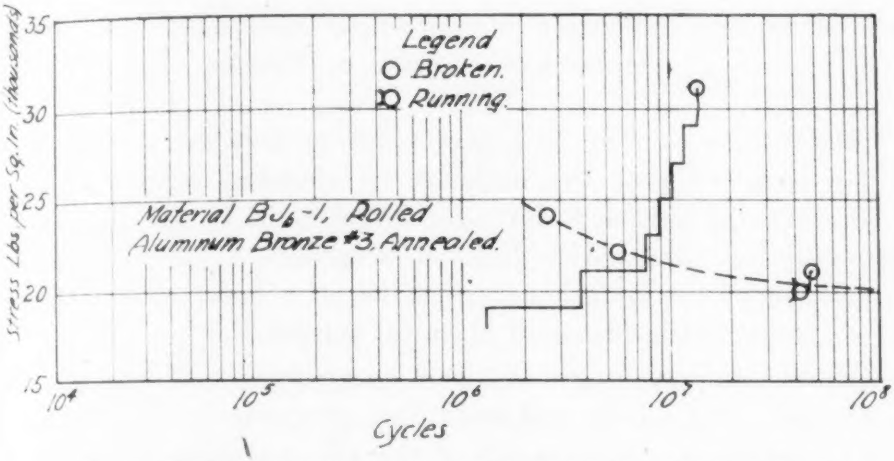

Fig. 4—Results of Rotating-Cantilever Tests of Annealed Aluminum Bronze.

CALCULATION OF ENDURANCE LIMITS OF ANNEALED ALLOYS FROM ENDURANCE LIMITS OF COLD-WORKED ALLOYS

On the basis of the above described preliminary investigation of the effect of cold working on the endurance properties of metals, it seems justifiable to assume that for all the alloys whose endurance properties were discussed in Part I, the effect of a moderate degree of cold working on the endurance limit is negligible. Proceeding on this assumption it is possible, therefore, to calculate the approximate endurance limits of the annealed alloys from the endurance limits of the alloys as rolled or drawn. Using the values for tensile strength of the annealed alloys as given in Table IV, and the values for tensile strength and endurance limit as given in Table IV of Part I, the values for endurance limit of annealed alloys as given in Table IV of the present paper have been calculated. Except for the few alloys whose endurance limit in the annealed condition has been experimentally determined, the endurance ratios as given in Column 7 of Table IV are the same as the endurance ratios for the same alloys as given in Table IV of Part I. The endurance limits of the annealed alloys will be used in estimating the effect of chemical composition on the endurance properties of alloys of nickel and of copper.

INFLUENCE OF CHEMICAL COMPOSITION ON ENDURANCE PROPERTIES OF ALLOYS OF NICKEL AND COPPER

Comparison of the endurance limits of annealed alloys is the best way to estimate the influence of chemical composition, although even in annealed alloys the influence of all variables other than chemical composition has not been entirely eliminated. A comparison of the endurance properties of a series of such alloys should reveal the influence of chemical composition.

In Fig. 5, percentages of nickel and copper have been plotted as abscissas, and tensile and endurance properties of annealed alloys as ordinates. Since many of the alloys contained important percentages of other elements in addition to nickel and copper, it was necessary to recalculate the percentages and represent these ternary or quaternary alloys by equivalent binary alloys. In these recalculations Guillet's "coefficients of equivalence" were used whenever possible. In some alloys, such as the copper-nickel-chromium alloy, material D, it was not possible to estimate the equivalence of chromium, since this element raises the strength of the alloy above the maximum of the curve of binary alloys of nickel and copper.

In Fig. 5, the upper line is the curve of tensile strength. The solid line rises rapidly from the point at the extreme left representing copper to the point representing constantan. At the extreme right, the solid line rises rapidly from the point representing nickel to the points representing monel metal.

Between abscissas of 45 and 80 per cent copper a maximum is evidently reached. Since the position of the maximum is not definitely established, this part of the curve is a dotted line. The maximum may possibly be at smaller copper percentage than that indicated by the dotted line.

The lower line of Fig. 5 is the curve of elastic limits. Although the form of this curve, as might be expected, is less defi-

Table IV
Relationship of Endurance Limits to Other Physical Properties

Material	Material Desig- nation	Cooled In	Drawn at Deg. Fahr.	Average Tensile Strength, Lbs., Per Sq. In.	Endurance Limit, Rotating Cantilever, Lbs. Per Sq. In.	Ratio of Column 6 to Column 5
1	2	3	4	5	6	7
Nickel, Cold-Rolled	A	†As Received		**166,200	40,000	0.24
Nickel, Cold-Rolled	A-5.5	Annealed		165,500	40,000	0.24
Nickel, Cold-Rolled	A-8.5	Annealed		160,000	40,000	0.25
Nickel, Cold-Rolled	A-11	Annealed		**142,600	49,000	0.34
Nickel, Cold-Rolled	A-14	Annealed		73,400	27,000	0.37
Nickel, Cold-Rolled	A-16	Annealed		70,400	25,500	0.36
Nickel, Hot-Rolled	AW-2	Annealed		§76,200	31,500	0.41
Monel Metal, Cold-Rolled....	BK-1	Annealed		77,100	26,000	0.33
Monel Metal, Cold-Rolled....	BH-2	Annealed		84,400	+29,500	0.35
Monel Metal, Hot-Rolled.....	AA-1	Annealed		77,300	+32,600	0.42
Constantan, Hot-Rolled	CE-1	Annealed		70,300	+34,500	0.49
Copper-Nickel-Chromium Alloy, Forged	D-1	Annealed		100,400	+35,000	0.35
Copper-Nickel-Tin Alloy, Cold-Drawn	CF-1	Annealed		57,800	+22,500	0.38
Copper-Nickel-Zinc Alloy, Hot-Rolled	CD-1	Annealed		51,100	+20,800	0.40
Copper-Nickel Alloy, Cold-Rolled	B-1	Annealed		44,400	+16,000	0.36
‡Copper-Nickel-Zinc Alloy, Cold-Drawn	CH	As Received		62,400	22,000	0.35
‡Copper-Nickel-Zinc Alloy, Cold-Drawn	CH-1	Annealed		54,600	....	...
‡Copper-Zinc-Nickel Alloy, Cold-Drawn	CG	As Received		58,700	17,000	0.29
‡Copper-Zinc-Nickel Alloy, Cold-Drawn	CG-1	Annealed		55,600	....	...
Copper, Cold-Drawn.........	CL-1	Annealed		31,500	+9,500	0.31
Alpha Copper-Tin Alloy, Cold-Drawn	CK-1	Annealed		48,800	+20,800	0.43
Phosphor Bronze, Rolled.....	F-1	Annealed		*47,400	....	...
Aluminum Bronze No. 1, Rolled	BJ-1	Annealed		57,800	+15,200	0.26
Aluminum Bronze No. 2, Rolled	BJa-1	Annealed		65,500	+18,400	0.28
Aluminum Bronze No. 3, Rolled	BJb-1	Annealed		62,300	20,000	0.32
Aluminum Bronze No. 4, Rolled	BJc-1	Annealed		89,000	+31,500	0.35
Alpha Copper-Zinc Alloy, Cold-Rolled	BP-1	Annealed		44,600	....	...
Alpha Copper-Zinc Alloy, Cold-Drawn	CJ-1	Annealed		46,500	+15,800	0.34
Muntz Metal, Hot-Rolled.....	BF	As Received		**65,100	....	...
Muntz Metal, Hot-Rolled.....	BF-8.4	Iced Brine	840	**65,600	18,000	0.27
Muntz Metal, Hot-Rolled.....	☐	......		58,600	16,200	0.28
Naval Brass, Hot-Rolled.....	U-1	Annealed		58,500	+18,500	0.31
Manganese Bronze, Hot-Rolled.	BG-1	Annealed		67,000	+16,500	0.24

☐No material available. On similar material, however, annealed results were 10% lower than on the material as received. These values, therefore, are 90% of the respective values obtained with the BF and BF-8.4 material.

Each static value is average of two determinations except as indicated.

*One determination only.

**Average of three determinations.

§Average of four determinations.

+Calculated from results obtained with some material as received.

†This had been annealed by the manufacturers at 550 degrees Fahr.

‡German silver.

nitely established than the curve of tensile strength, apparently the two curves have about the same form. The lower curve and the upper curve evidently reach a maximum at about the same abscissa.

The curve of endurance limits rises rapidly from the abscissa representing copper to that representing constantan. From about this point it descends less rapidly and almost in a straight line to the abscissa representing nickel. In Part I attention was called to the fact that constantan has the highest endurance ratio of all the non-ferrous metals tested. Its endurance ratio is about equal to that of steel. Possible causes for this unusually high ratio were

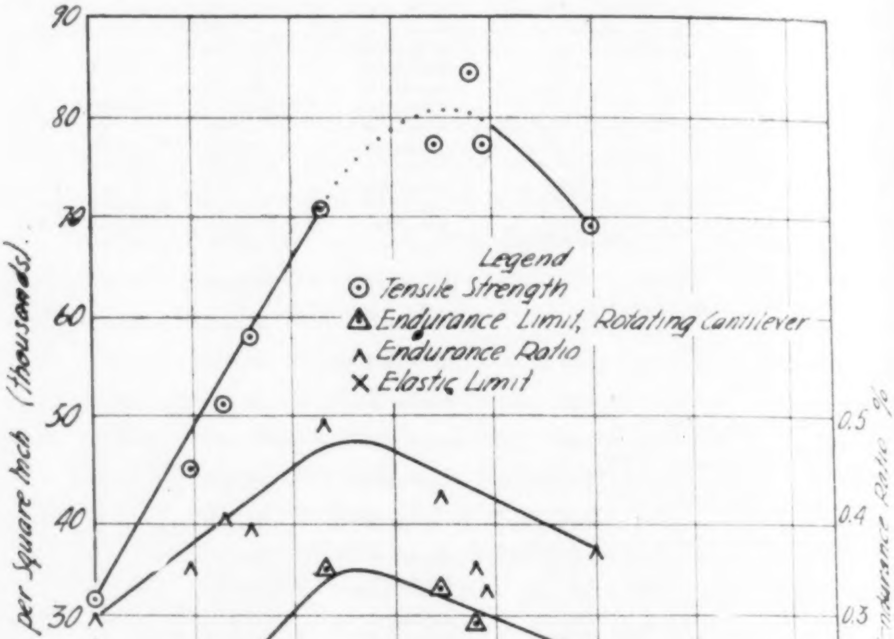

Fig. 5—Effect of Composition on Physical Properties, Nickel-Copper Alloys (Annealed).

discussed in Part I. The curve of endurance limits in Fig. 5 of the present paper, however, seems to indicate that the high endurance ratio may be an inherent property of an alloy of this composition.

The present use of constantan is based on its electrical, rather than its physical, properties. Its temperature coefficient of electrical resistance is zero. The curve of electrical resistance of the alloys of nickel and copper, however, has a decided maximum at about 50 per cent nickel. The results of endurance tests seem to indicate that the nickel-copper alloy of maximum electrical resistance is the alloy of maximum endurance limit. These tentative conclusions, however, need to be tested by means of endurance tests on a series of binary alloys containing precentages of nickel ranging from 45 to 65.

The form of the curve of endurance ratios is similar to that of the curve of endurance limits. It is probable that two of the points representing monel metal are too low. The variation in endurance properties between different specimens of this alloy is so great that it is difficult to make a close estimate of the average endurance properties.

INFLUENCE OF CHEMICAL COMPOSITION ON THE ENDURANCE PROPERTIES OF COPPER-TIN ALLOYS

Since only the alpha alloy containing 5 per cent tin was available, it is impossible to make a complete graph of copper-tin alloys. The results available are plotted in Fig. 6. The results show that increase in the tin percentage of the alpha alloy increases the tensile strength, proof stress, elastic limit, and endurance limit. The increase in the endurance limit is more than proportional to the increase in tensile strength. The best copper-tin alloy for endurance properties is probably a nearly saturated alpha alloy, having about 12 per cent tin.

INFLUENCE OF CHEMICAL COMPOSITION ON THE ENDURANCE PROPERTIES OF COPPER- ZINC ALLOYS

Fig. 7 illustrates the effect of increase of percentage of zinc on the physical properties of alloys of copper and zinc. Although only one alpha alloy was available, the trend of each of the graphs is evident. Increase of tensile strength, proof stress, and elastic limit, is more than proportional to the percentage of zinc. The endurance limit, however, does not increase in proportion to the increase in tensile strength. The endurance limit apparently

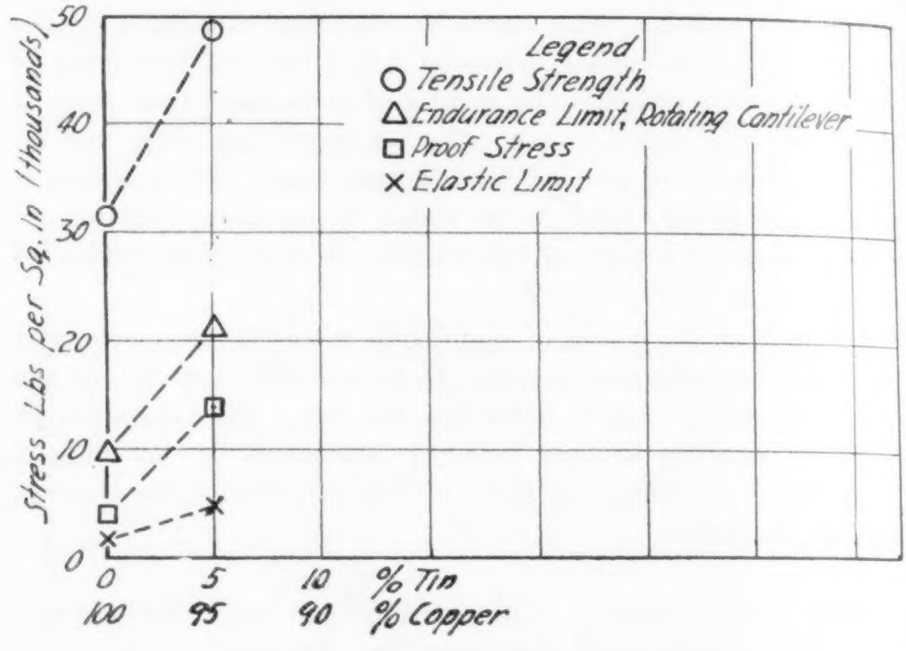

Fig 6—Effect of Composition on Physical Properties of Copper-Tin Alloys (Annealed).

reaches a maximum in the saturated alpha alloy having about 36 per cent zinc. The endurance limit of the alloys of duplex microstructure, such as Muntz metal, Naval brass, and manganese bronze is no higher than that of the saturated alpha alloy and is little if any higher than that of the alloy having about 28 per cent zinc. The curve of endurance ratios consequently slopes downward to the right of an abscissa representing about 36 per cent zinc.

A comparison of Figs. 6 and 7 shows that the addition of zinc to copper has a much less favorable influence on the endurance limit than does the addition of tin to copper. Whereas the addition of 5 per cent tin more than doubles the endurance limit, the addition of 28 per cent zinc increases the endurance limit only about 80 per cent. The saturated alpha copper-tin alloy is probably greatly superior in endurance properties to the saturated alpha copper-zinc alloy.

ENDURANCE PROPERTIES OF COPPER-NICKEL-ZINC ALLOYS

In Part I results were presented of tests of a copper-nickel-zinc alloy, material CD, containing 20 per cent nickel and 5 per cent zinc. Since the percentage of zinc in this alloy is so small it was assumed that the alloy could be reduced by calculation to an equivalent binary alloy of copper and nickel. On this assumption the calculated endurance limit of the annealed alloy was plotted in Fig. 5. As shown in Fig. 5, the endurance limit of the recalculated alloy falls near the line representing average endurance properties of binary alloys of copper and nickel.

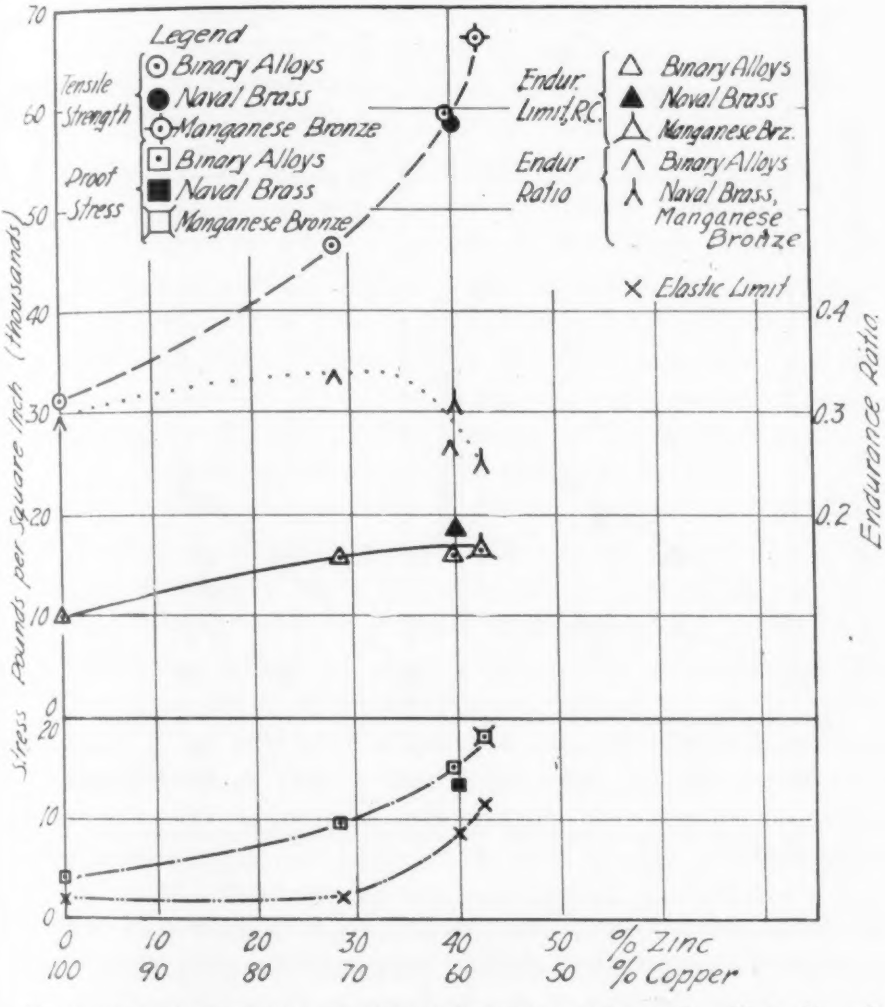

Fig. 7—Effect of Composition on Physical Properties of Copper-Zinc Alloys (Annealed).

Results of endurance tests of two additional copper-nickel-zinc alloys are presented in Fig. 3. The chemical composition of each of these alloys is given in Table I. Since the alloys contain such large percentages of zinc and nickel they cannot by calculation be reduced to equivalent binary copper-nickel-zinc alloys.

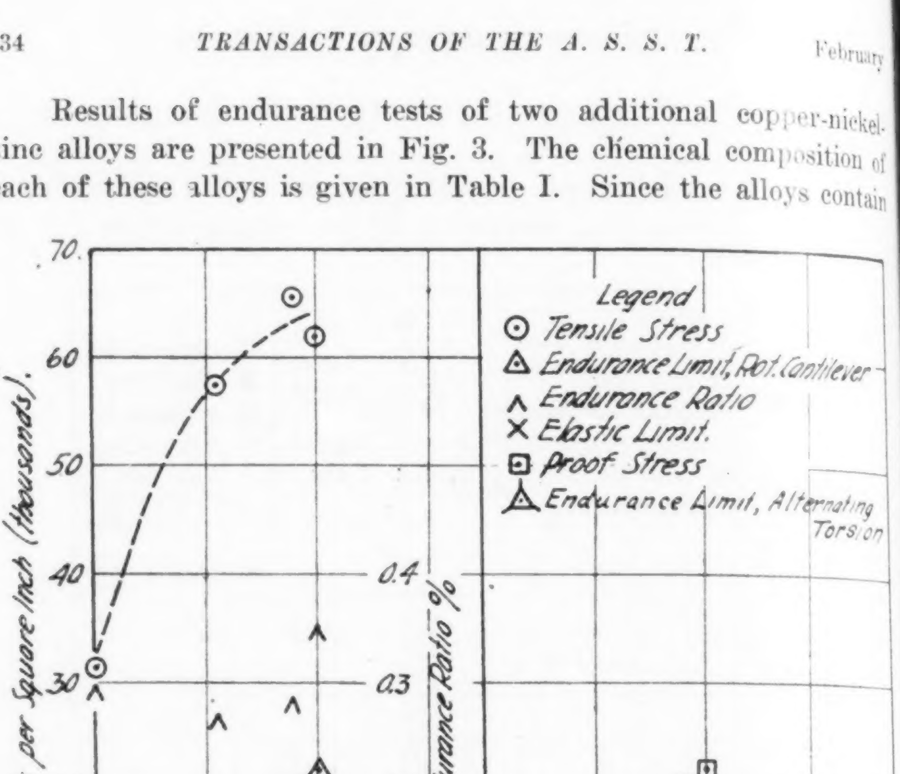

Fig. 8—Effect of Composition on Physical Properties of Copper-Aluminum Alloys (Annealed).

As shown in Fig. 3 the endurance limit of material C11 is about 22,000 pounds per square inch. By reference to the graph of endurance limits in Fig. 5 it is evident that the endurance limit of this alloy is considerably higher than that of a copper-nickel alloy having the same percentage of nickel. By reference to Fig. 7 it is also evident that the endurance limit of this alloy is much higher than that of any annealed copper-zinc alloy. On the assumption that the effects of nickel and zinc on the endurance limit are additive, and that the effects are as shown in Figs. 5 and

7, the value calculated is about equal to the actual endurance limit of the ternary alloy. As shown in Fig. 3 the endurance limit of material CG is about 17,000 pounds per square inch. As shown in Figs. 5 and 7, this endurance limit is about equal to that of a copper-nickel alloy having the same percentage of nickel and to that of a copper-zinc alloy having the same percentage of zinc. Evidently in this ternary alloy the effects of nickel and copper on the endurance limit cannot be considered additive.

The results would seem to indicate, therefore, that in copper-nickel-zinc alloys, in which the proportion of copper predominates, the effects of nickel and zinc on the endurance limit are additive unless the proportion of zinc greatly exceeds that of nickel. If the proportion of zinc greatly exceeds that of nickel the effect of nickel on the endurance limit is negligible and the endurance limit is practically that of a brass having the same percentage of zinc.

INFLUENCE OF CHEMICAL COMPOSITION ON THE ENDURANCE PROPERTIES OF COPPER-ALUMINUM ALLOYS

The influence of varying proportions of copper and aluminum in the binary alloys of these two elements is illustrated by Fig. 8. The results would seem to indicate that within the limits of the investigation the effect of aluminum on the rotating-cantilever endurance limit is approximately proportional to the aluminum percentage. The effect of aluminum on the alternating-torsion endurance limit and on the tensile strength is apparently not in proportion to the aluminum percentage. Increase in percentage of aluminum beyond the limit of the alpha solid solution apparently has little effect on the alternating-torsion endurance limit. In this respect copper-aluminum alloys are similar to copper-zinc alloys. Additional experiments, however, are needed to establish definitely the influence of chemical composition on the endurance properties of the alloys of copper and aluminum.

PRACTICAL APPLICATION OF RESULTS OF INVESTIGATION OF EFFECT OF CHEMICAL COMPOSITION ON ENDURANCE PROPERTIES

Although the endurance limit of an alloy may be increased by cold working, efficient increase by this method is limited. There is a decided advantage, therefore, in so adjusting the chemical composition as to obtain alloys that have as high as possible an endurance limit in the annealed condition. For this purpose the most promising of these non-ferrous alloys are the alloys of nickel and copper, especially those having 45 to 65 per cent nickel. The copper-zinc alloys show the lowest endurance properties of any of the four series of binary alloys investigated. Of intermediate properties are copper-tin and copper-aluminum alloys.

Acknowledgment is hereby made of the encouragment in this work received from Captain P. B. Dungan, U. S. N., Officer in Charge, U. S. Naval Engineering Experiment Station, and of the assistance received from G. F. Wohlgemuth, associate metallurgist, and to J. L. Basil and A. P. Vandermast, laboratorians at the Naval Experiment Station.

SOME REVELATIONS BY DEEP ETCHING

By J. Fletcher Harper

Abstract

This paper discusses the acid etching of forgings and castings for the purpose of inspecting the soundness and fitness for use of the materials under examination. The author draws certain conclusions as to the advantages of this method of inspection. Chief among the advantages are the identification of the presence of fine hair-line cracks and solid nonmetallic inclusions. These will be opened up into deep pits or slots as a result of the acid etching. To a considerable extent it is possible to identify the method of manufacture by which the particular specimen under examination had been manufactured in the steel mill.

The text of this paper embraces some experiments conducted by the writer prior and subsequent to the work done by Hoffman and Waring[1] on the deep etching of rails, published in 1919. Although some of our readers may not agree with all of the points brought out in the present paper, it is hoped that what is given may be of help as a method of solving some of the so-called steel mysteries.

In the early part of 1918, our company was suddenly confronted with a number of rejected forgings. These forgings consisted chiefly of shafts which were made of 3.00 to 3.50 per cent nickel steel, and subject to our specification class "FS-D," which has the following requirements:

Elastic limit of 50,000 pounds per square inch
Ultimate strength 80,000 pounds per square inch
Elongation in 2 inches—25 per cent
Reduction of area —45 per cent

We had been producing these forgings for a considerable

Acknowledgment is made to Henry Freeman and R. S. MacPherran of the Allis-Chalmers Manufacturing Company for their assistance in these experiments.

[1] Hoffman and Waring on "The Deep Etching of Rails," presented before the annual meeting of the American Society for Testing Materials, June, 1919.

A paper presented before the Cleveland chapter of the Society. The author, J. Fletcher Harper, is Research Engineer, Manufacturing Department, Allis-Chalmers Manufacturing Company, Milwaukee.

period of time and had no difficulty in meeting the specification with a standard heat treatment. These defective forgings, however, were revealing conditions such as are shown in Table I. It will be observed that in all but one instance the materials met the specification for elastic limit and tensile strength, but were low in elongation and reduction of area. To cope with the situation, we altered the temperature of annealing, the temperature of quenching and the temperature of tempering, but with no better results. Chemical analyses were made of these materials, and in all cases

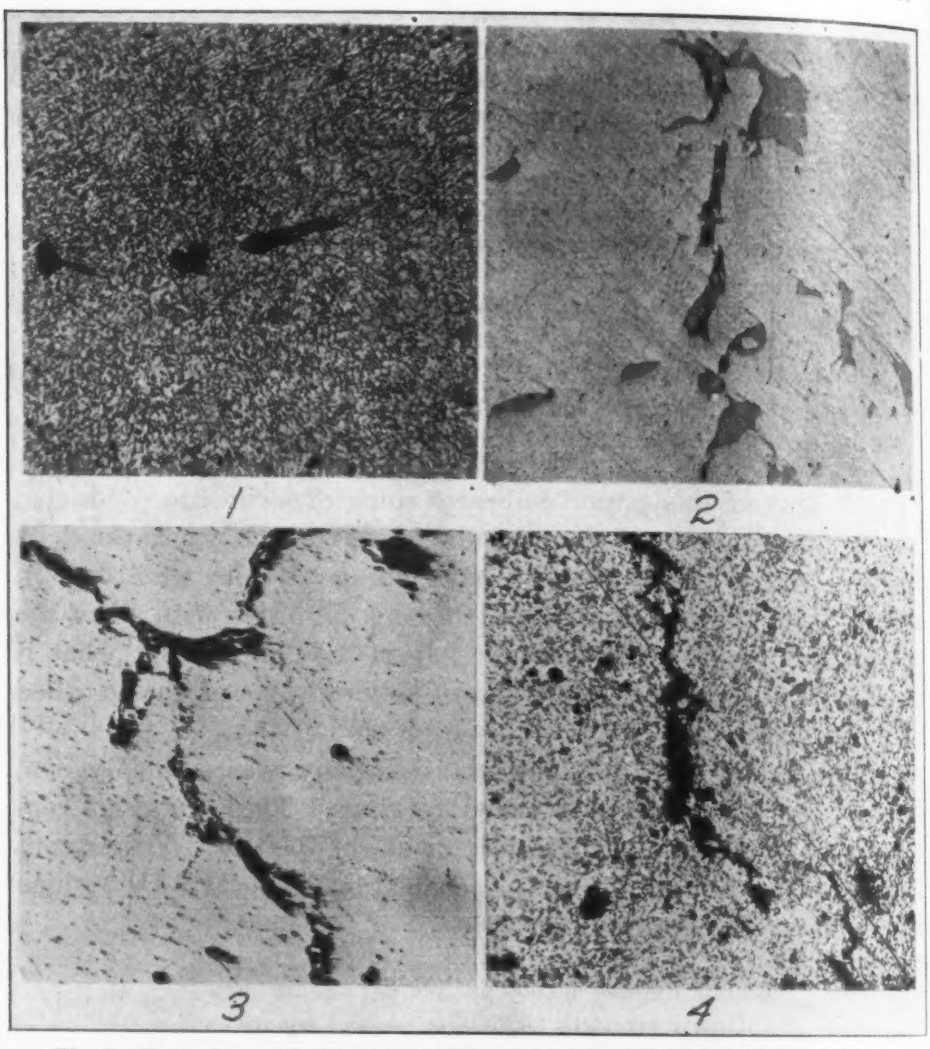

Fig. 1—Photomicrograph of a 3.50 Per Cent Nickel Steel Etched with Picric Acid, 100x With the Exception of the Inclusions, this Structure is Quite Satisfactory. Fig. 2—Photomicrograph of a Similar Piece of Steel Showing Minor Sonims and a Large Fissure, 100x. Fig. 3—Photomicrograph of a 3.50 Per Cent Nickel Steel, Unetched, 100x. Fig. 4—Photomicrograph of the Same Specimen, Etched, Showing a Large Fissure and Numerous Sonims.

the composition of the steel was as specified. Microscopic examinations revealed good structures with the exception of some minor inclusions and cracks in certain sections, but otherwise entirely free from defects. The photomicrographs of the defective areas of some of the steels examined are shown in Figs. 1, 2, 3 and 4.

Table I

Physical Tests of Defective Forgings

Test No.	Elastic Limit lbs. per sq. inch	Ultimate Strength lbs. per sq. inch	Per Cent Elongation in 2 inches	Red. Area	Fracture
Required	50000	80000	25	45	
1065	57000	95000	14	17	Angular
1065 C.	62800	92700	18.5	28	Angular
1065 A.	52900	85900	21	27	Angular
1288 B.	55800	86520	6	10	Angular
1075 A.	56900	82000	15	21	Angular
1064	48550	85150	15	24	Angular

Upon casual examination of these photomicrographs it would appear that the difficulty was due to dirty steel and that the results of the physical tests bore out this conclusion. These, however, are a few of the worst photomicrographs which were taken. Hundreds of samples were examined, some of which showed only a minor number of sonims (solid non-metallic impurities), others showed a major number of sonims in one section and a minor number of sonims in an adjacent section, and still others were entirely free from inclusions. It was at this point of our investigation that our first work on deep etching with acids started. Deep etching was accomplished by heating a piece of steel of definite size for a given time, in a solution of concentrated hydrochloric acid.

It was found that by duplicating deep acid-etching conditions as nearly as possible in each test, we were able to make excellent comparisons between samples. In these etching tests it was noted that steels of different analyses varied in solubility and that the rate of solubility varied according to the amount of mechanical work which had been done upon the piece. Different annealing temperatures on the same steel caused differences in solubility. It was noted that steels made by the acid open hearth, basic open hearth or electric furnace methods could be distinguished one from the other, due to differences of solubility of steels of similar analysis. It was with great ease that samples taken from forgings made from sand-cast and chill-cast ingots could be distinguished.

These points are brought out simply to show the wide range and the possibilities of comparison of similar samples subjected to the deep acid etch. Figs. 5, 6, 8 and 9 show the results of some deep etching tests made on bars cored from forgings. Fig. 5 shows a bad surface condition with considerable pitting following the acid etch. The physical test properties of this specimen is shown in Table I, test 1064. The elastic limit, elongation and reduction of area are below the specifications. Photomicrographs of this speci-

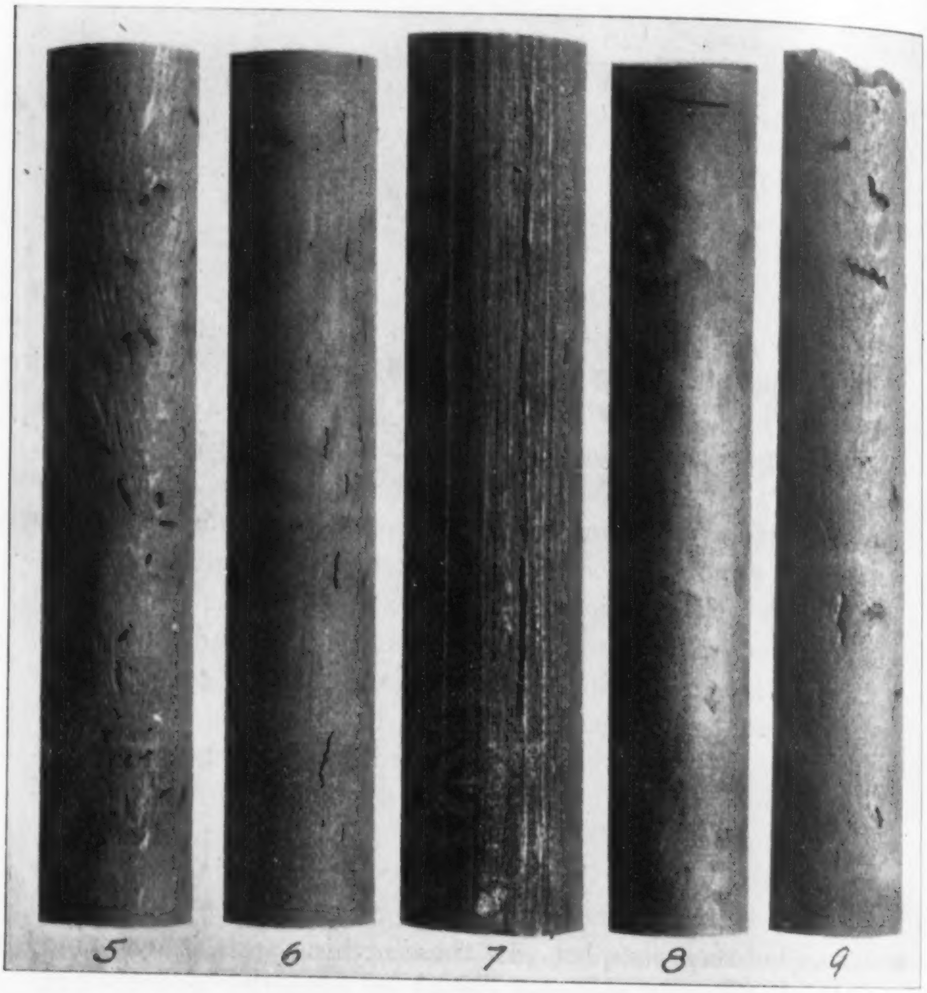

Fig. 5—Photograph of a Deeply Etched Bar Showing Many Deep Pits on the Surface. Fig. 6—Photograph of a Deeply Etched Bar Showing Fewer Surface Pits and Cracks. Fig. 7—Photograph of a Deeply Etched Rolled Wrought Iron Bar Showing a Very Rough Surface Resulting from the Etching Away of the Elongated Slag Inclusions. Fig. 8—Photograph of a Deeply Etched Sound Bar Showing an Absence of Pits and Cracks with the Exception of a Minor Fissure at the Top of the Bar which was Caused by Mechanically Breaking the Bar. Fig. 9—Photograph of a Deeply Etched Bar Showing Very Deep Surface Pits; Photomicrograph of This Bar is Shown in Fig. 3.

men are shown in Figs. 3 and 4. It will be noted that these three different methods of test lead to the same verdict, that is, that the steel was dirty and contained many sonims.

Fig. 6 shows a specimen with less pronounced pits than those of Fig. 5. In order to establish whether or not these pits were in the center of the specimen, as well as on the surface, the same specimen was cut transversely and longitudinally and then deeply etched. After etching, the specimens were closely examined and it was found that where a fissure or pit existed on one segment there was a corresponding pit on the matching segment. Pitting occurred on interior sections as well as on the surface.

Fig. 7 shows a bar of rolled wrought iron after it has been deeply etched. The rough fluted condition of the surface is due to the fact that the slag lines or inclusions in the bar have been eaten away by the acid, thus revealing the piling.

Fig. 8 shows a sound bar of steel after it has been deeply etched. With the exception of the fissure at the extreme upper end of the bar, this specimen shows no pitting or fissures. The crack at the top of the bar was produced by mechanically breaking the specimen, which upon deeply etching was enlarged to a fissure. Such hair line cracks which open up as fissures during deep acid-etching may be produced by extreme internal stress, or by impact. It has always been found that these fissures occur at right angles to the line of stress in the material and are apparently always intercrystalline as compared with intracrystalline cracks which are inherent in the material due to conditions of manufacture.

Some time subsequent to making these tests we were having difficulty in hardening certain areas of a gas engine cam shaft. These soft areas always appeared in the same location on the shaft regardless of the method or condition of heat treatment. Deep etching of numerous specimens cut from different cam shafts revealed the condition as shown in Fig. 10. The parting line of the forging die was at the part of this cam which was giving difficulty in hardening. In the forging of a cam shaft, due to the nature of its shape, the material flows in a horizontal direction until it meets the closed faces of the die, or until the flash chills. The material then flows perpendicularly upward and downward to fill the die. If ample curvature is not provided, or the dies are not brought down with the minimum thickness of flash, a number of fiber-like ends of worked-material are left on the forging at the parting of the dies. The mechanical working of steel between dies tends to move non-metallic particles toward the parting line of the die, resulting in a concentration of these inclusions at the point where the best metal is wanted. Further examination of these specimens showed that it was evident that the trimmer die was not functioning properly and was tearing the metal in shearing, resulting in voids or fissures at the parting line of the dies. To properly carburize and harden such material is of course quite impossible.

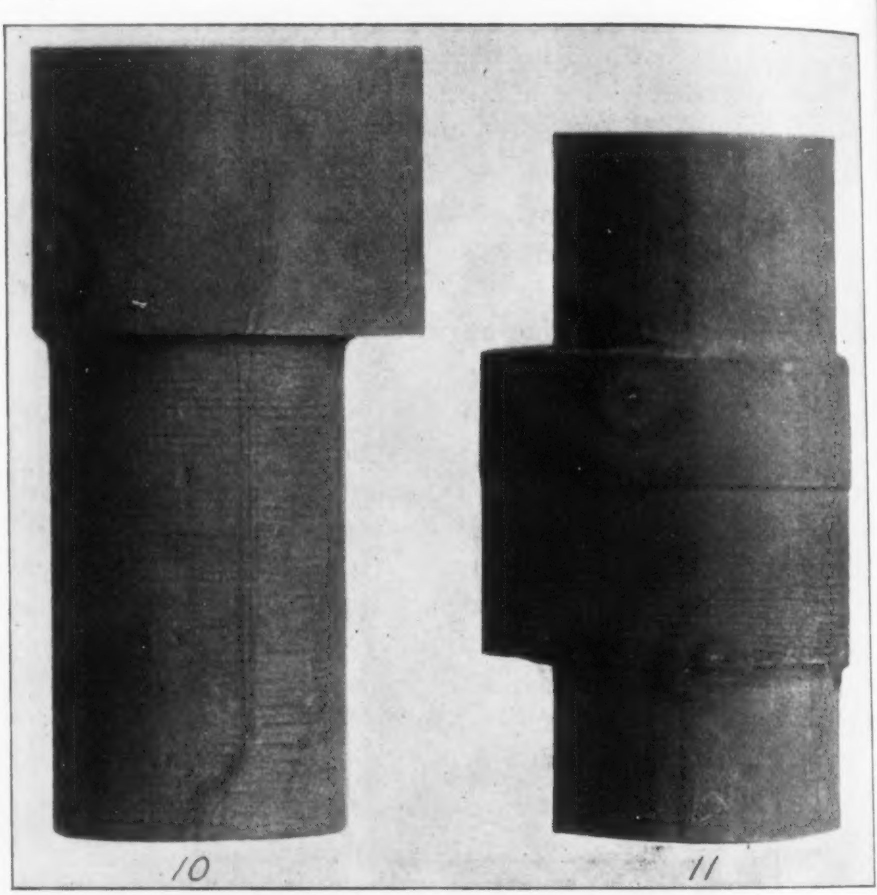

Fig. 10—Photograph of a Deeply Etched Cam. It will be Noted that Deep Lines Appear on this Material at the Parting Line of the Die. Fig. 11—Photograph of a Deeply Etched Hardened Cam Containing Many Grinding Cracks Due to the Use of an Improper Grinding Wheel, and Improper Feed or Speed.

Fig. 11 shows a deeply etched hardened cam which contains many grinding cracks resulting from the use of an improper grade of grinding wheel or an improper feed and speed of grinding.

These results can also be produced by the use of proper grinding equipment if the structure of the material contains excess free cementite near the surface.

It has been found that only in rare cases could surface cracks be produced by deep etching alone and then only on materials containing high internal stresses due to drastic heat treatments. Similar cracks usually appear upon aging such hardened material, due to the fact that the material has many internal stresses which are relieved upon long standing or aging. Deep etching accelerates these aging cracks.

SUMMARY

In summing up the advantages and the applications of deep etching with acids to the examination of the materials of construction, we find that this method will reveal:

1. That steels of varying chemical analysis will show varying rates of solubility in the acid.
2. That steel with heterogeneous composition will have a relatively rougher surface condition due to the differences in solubility of the different parts of the specimen. Sonims and cracks will produce pits and slots.
3. That the same steel varies in solubility when given various heat treatments.
4. That it is possible, to a certain extent, to identify the method of manufacture of steels of similar analysis due to their varying rates of solubility in the acid etch. The fact that there are differences in rates of solubility of these steels may lead to the explanation of the differences in physical properties of acid open hearth, basic open hearth and electric furnace steel of apparently identical composition.
5. That forgings made from chill-cast and sand-cast ingots show a marked difference in cleanliness and a slight difference in solubility.
6. That incipient cracks in all cases of defective steel examined, were intracrystalline and in all directions although tending to be elongated in the direction of the mechanical work.
7. That cracks occurring in steel due to mechanical strain appear in a direction perpendicular to the stress in the material and in all cases examined, were intercrystalline.

SYMPOSIUM ON HARDNESS TESTING HELD AT SIXTH ANNUAL CONVENTION OF THE SOCIETY, BOSTON, SEPTEMBER, 1924

IN opening this symposium, Chairman H. P. Hollnagel announced that each of the papers to be given at this meeting would be read and the discussion of each paper would follow after they had all been presented.

The papers were then given in the following order: "Comparison of Brinell and Rockwell Hardness of Hardened High Speed Steel," by S. C. Spalding (paper published in the October issue of TRANSACTIONS); "The Relation of Hardness and Impact Measurements to Performance," by G. W. Webster (this paper has not been made available for publication in TRANSACTIONS); "Relation Between Rockwell and Brinell Hardness Scales," by I. H. Cowdrey; "The Ball Indentation Hardness Test," by S. L. Hoyt (published in September TRANSACTIONS); and "Report on Hardness Testing Work of A. S. M. E. Committee on Cutting Metals," by A. E. Bellis.

Inasmuch as two of the four papers have already been published and the third one—that of G. W. Webster—withheld from publication, the remaining paper by I. H. Cowdrey is published herewith:

RELATION BETWEEN ROCKWELL AND BRINELL HARDNESS SCALES

BY I. H. COWDREY

IN view of certain very definite statements which have appeared in the TRANSACTIONS within the last year it is with hesitancy that the subject under discussion is approached. Nevertheless it seems that the results of research carried out by several students, under the personal direction of the writer, at the Testing Materials Laboratory of the Massachusetts Institute of Technology[1] warrant a further discussion of the relation between the hardness values for various materials as determined by the Rockwell Hardness Tester and the Brinell Machine.

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[1] Theses at Massachusetts Institute of Technology by F. de la Macorra, 1923, and R. S. Hamilton and W. J. Bagby, 1924.

The Symposium on Hardness Testing was under the direction of the Hardness Testing Committee of the National Research Council of which committee H. P. Hollnagel is chairman.

A paper presented before the Boston Convention of the Society, September, 1924. The author, I. H. Cowdrey, is assistant professor of testing materials at Massachusetts Institute of Technology, Cambridge.

For many years the Brinell method of hardness determination was the most accurate and for most purposes most satisfactory. It has become more or less standard in many factories and heat treatment specifications often include Brinell hardness. With the advent of the Rockwell hardness tester it became evident that certain of the disadvantages of the Brinell method had been overcome. During the past few years there has been a constant query in the minds of many, concerning the possibility of the existence of some fixed relation between the hardness as obtained from the two machines. Some attempt at a purely theoretical and mathematical deduction came to the attention of the writer about two years ago. This however did not seem satisfactory nor did it prove out very well in practice. Since both machines depend upon the resistance which a material offers to penetration by a steel ball it would still seem that some relation should exist. The sizes of the test ball, however, are very different, as well as the pressures: hence the units expressing the hardness values are entirely different.

The call for help from the steel treaters was so insistent that the writer felt urged to attempt the solution of this troublesome question. Early in 1923 this research was started and continued until May of this year (1924).

Nearly three hundred separate samples of metal were studied. These were both ferrous and nonferrous and included overstrained, cold-worked and heat treated material. Among the metals under observation were, lead, copper, zinc, aluminum, brass, bronze, gray and white cast iron, wrought iron, steel castings, simple carbon steel, tool steel and stellite. These gave hardness values ranging as follows:

Brinell Hardness Number	30 to 800
Rockwell Reading, $\frac{1}{16}$-inch ball	—26 to 125
Rockwell Reading, diamond cone	—46 to 63

In determining the hardness values, smooth flat surfaces were always used in order to minimize the effect of surface conditions. In general five to seven readings were made with the Rockwell machine and at least two for the Brinell value.

For most of the materials, Rockwell tests were also made using

$\frac{1}{8}$ and $\frac{1}{4}$-inch balls. In view of the fact that these sizes are no longer recommended for use in commercial practice the data will not be presented in this paper. The equations connecting these tests with the values obtained with the Brinell machine will appear later.

Special steel balls were used for the very hard material under the Brinell test and the surfaces of the balls were closely observed in order that no test would be made after any appreciable flattening of the ball had been produced. Such flattening was never observed where the special balls were used.

From the data thus accumulated several interesting relations may be deduced. Of these, three are of particular interest, namely: the relation between R_{16} and B, R_c and B, and R_{16} and R_c, where

R_{16} means Rockwell hardness using a $\frac{1}{16}$-inch ball and a 100 kilogram major load.
R_c means Rockwell hardness using a diamond cone and a 150 kilogram major load.
B means Brinell hardness number.

later on will also appear:

R_4 meaning Rockwell hardness using a $\frac{1}{4}$-inch ball and a 100 kilogram major load.
R_8 meaning Rockwell hardness using a $\frac{1}{8}$-inch ball and 100 kilogram major load.

The three relations just noted are shown graphically by the plots in Figs. 1 and 2. In the plot showing Rockwell hardness with a $\frac{1}{16}$-inch ball the points plotted with a circle were obtained by Mr. de la Macorra during the early part of the research while those marked with a cross are from check tests made using an entirely different set of metals during the latter part of the study by Messrs. Hamilton and Bagby. Data for all other graphs were obtained by the last two mentioned observers.

Even a casual inspection of these graphs shows that there is undoubtedly some general law connecting the items in question. It is very evident that the relation is not a very simple one. The plotted points certainly do not lie on anything like a straight line.

It is also true that the observed points do not lie absolutely along a single line. This is invariably the case with experimental data.

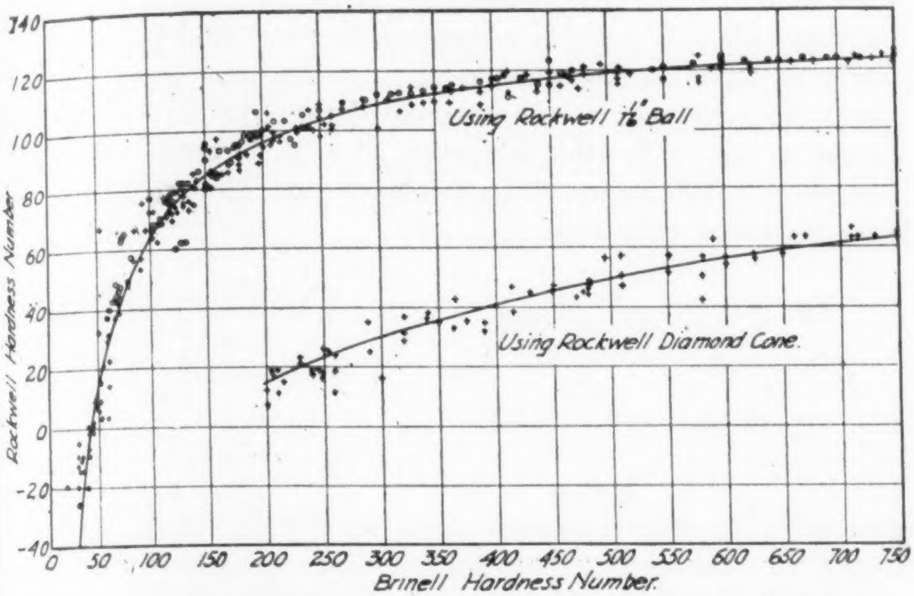


Fig. 1—Graph Showing Relation Between Brinell Hardness and Rockwell Readings.

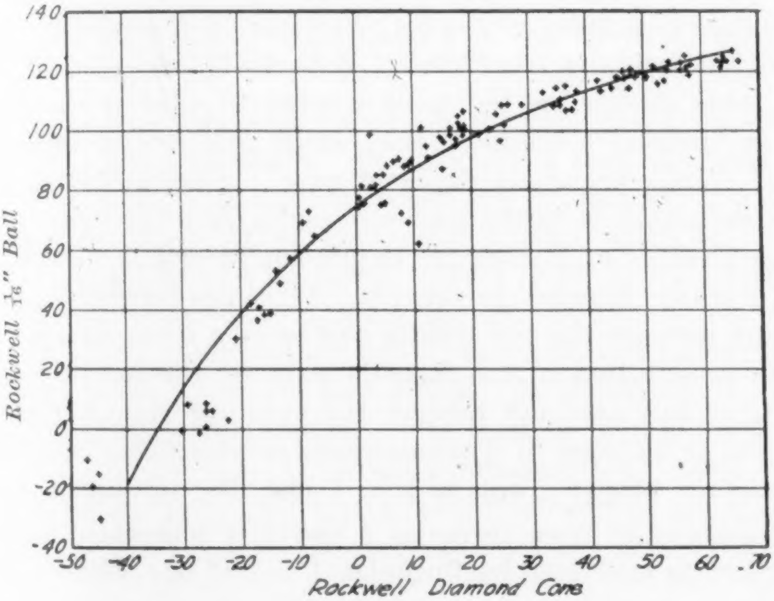


Fig. 2—Relation Between Rockwell Readings When Using $^1/_{16}$-Inch Ball and Standard Diamond Cone.

The surprising feature is, not this variation, but the fact that the band including the points is so narrow. Variation is a feature common to all material. Every heat treater knows that there is no such thing as perfection, neither is there any constancy to be found in metals. Realizing this, it is then very proper that an attempt should be made to express the very evident law of variation by some mathematical relation or formula which shall represent the best mean of the observed data. The mathematical processes necessary for the derivation of such formulas would be out of place in this paper. The results of such analysis however yield the following relations:

$$(1a)\quad R_{16} = \frac{B - 42}{0.154 + 0.0074B} \qquad\qquad (1b)\quad B = \frac{R_{16} + 273}{6.49 - 0.048R_{16}}$$

$$(2a)\quad R_c = 88.3\ B^{0.161} - 192 \qquad\qquad (2b)\quad B = \left\{\frac{R_c + 192}{88.3}\right\}^{6.21}$$

$$(3a)\quad R_{16} = \frac{R_c + 35}{0.47 + 0.0048R_d} \qquad\qquad (3b)\quad R_c = \frac{R_{16} - 74.5}{2.13 - 0.01R_{16}}$$

Formulas (1a) and (1b) are not unduly complex. Translations from Rockwell to Brinell values by use of them are purely a question of simple arithmetic. This simplicity might be predicted when the facts are considered. With both machines, the impression made during the test is of a spherical character so it should not be difficult to connect the results without undue complications. When using the diamond cone for the Rockwell machine the comparison is made between results obtained from a spherical impression and from an impression which is a section of a cone slightly blunted at the tip. It is not surprising that the relation between the two results will be of a more complex nature. While substitution in the formula requires the use of a logarithmic table this need not hamper the practical man who may have recourse to his copy of TRANSACTIONS in which this paper appears and use the proper graph in Fig. 1 just like any other chart.

Theoretically from formulas 1 and 2 it is possible to establish the relations expressed by formulas 3 (a and b). Such a combination will result in a formula of still greater complexity. The relation between the Rockwell values using the $\frac{1}{16}$-inch ball and using the diamond cone have been plotted in Fig. 2. This plot has a form closely resembling the plot R_{16} — B of Fig. 1. While the formulas (3a) and (3b) are slightly approximate it will be noted that the line constructed from them averages the points on the graph with fair accuracy. The greatest discrepancies between the formula and the observed data appear in the lower range which in general represents nonferrous material.

The makers of the Rockwell machines recommend the cone for the harder metals only. Hence in the range to which it would apply, the formula is probably sufficiently accurate and its use necessitates arithmetical processes only. The relations previously mentioned connecting the Brinell values with the results obtained by using the larger balls with the Rockwell machine are expressed by the following formulas:

$$\text{(4a)}\quad R_8 = \frac{B - 29.5}{.0077B} \qquad \text{(4a)}\quad B = \frac{30}{1.015 - 0.0078R_8}$$

$$\text{(5a)}\quad R_4 = \frac{B - 20}{0.0076B - 0.025} \qquad \text{(5b)}\quad B = \frac{800 - R_4}{40 - 0.305R_4}$$

It is fully understood that these formulas have no commercial significance: they are however inserted for the sake of general interest. It might be noted that with the softer materials the larger balls of the Rockwell testing machine seem to give results slightly more consistent than those obtained by using the $\frac{1}{16}$-inch ball.

From time to time the Rockwell machine has been criticized on a basis of inconsistency. Occasionally a user has been known to hold that he found unexpected and apparently inexplicable vagaries in the results of tests on a sample which he "thought ought to show uniform hardness." This phase of the question has also been investigated. It must be ever held in mind that the area presented to the $\frac{1}{16}$-inch ball of the Rockwell testing machine is extremely small even in soft metals. As the hardness increases, this area becomes even smaller. The thought then naturally arises that, perhaps even in "apparently homogeneous" material there may actually exist local variations in hardness. If these areas of local variation are of the magnitude of the area explored during the Rockwell test, it is readily conceivable that variations may appear between successive Rockwell readings, while the larger area under load with the Brinell machine may completely obscure these variations. In order to test the validity of this hypothesis a sample of very coarse grained brass was studied. The surface of the sample, polished and etched, showed very clearly the individual grains. These grains were sufficiently large to permit Rockwell hardness determinations on individual grains. In most instances it was possible to make two or even three tests on a single grain. A sketch of the surface of this sample appears in Fig. 3, drawn about twice the actual size, and the approximate locations of the different Rockwell tests have been charted upon it.

The results of these tests appear below:

Location	Hardness R_{16}	Location	Hardness R_{16}
2	19.5	23	38.0
3	19.1	24	38.5
19	19	10	42.1
4	28	6	43.5
5	29	8	43.0
7	29.5	9	45.0
11	27	12	45.2
13	26.5	14	46.8
18	28	16	47.5
22	28	15	48.6
1	31.4	17	48.8
20	31.2		
21	32.2		

A careful study of these results is very illuminating.

1. It will be noted that they fall roughly into four groups of values.
   a. Rockwell hardness about 19.
   b. Rockwell hardness about 29.
   c. Rockwell hardness about 40.
   d. Rockwell hardness about 48.
2. Let it be observed that the greatest hardness is over 150 per cent higher than the lowest value. This would seem almost unbelievable when it is considered that the sample was scarcely 1" in its greatest dimension.
3. The values bracketed in each case were obtained from the same grain or grains of obviously the same physical characteristics.
4. A study of points 20, 21, 23 and 24 suggests that possibly a varying thickness of the overlying grain or variation in the character of the subjacent grain may affect the apparent hardness number.

It must be admitted that the above results are somewhat abnormal. They are however very significant. If, under admitted abnormal conditions, a variation of 150 per cent appears, is it not reasonable to expect a variation of perhaps 5 per cent or 10

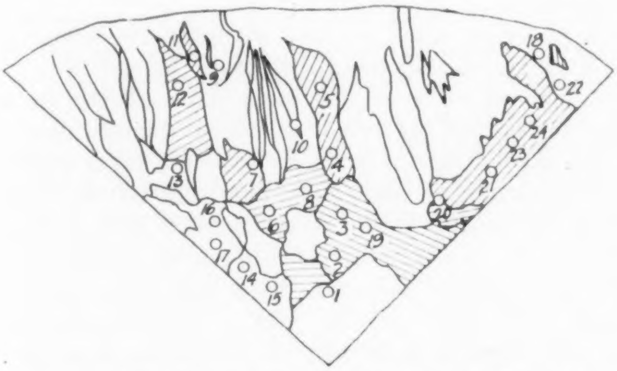


Fig. 3—Diagram of Brass Surface Used in Study of Effect of Grain Character on Rockwell Hardness.

per cent under very normal conditions? Should the investigator then complain if his Rockwell readings vary a few points each side of the mean when exploring a surface of considerable extent? It is the firm opinion of the writer that when the Rockwell test shows a reading of 85, the hardness of the material *at that point* is 85 even though a reading of 90 may be observed at some point not very distantly removed. This phenomenon also tends to explain the slightly better consistency of reading with the 1/8" and 1/4" ball for the softer metals which are likely to be of greater grain size.

The field indicated by the title of this paper has by no means been exhausted, and further investigation may well be undertaken. A more extended research using the diamond cone would be very desirable. The results have been obtained by means of a single machine for each type of test. Further study comprising comparisons of results obtained with many machines would be valuable. The Rockwell method, possibly modified, might be extended to permit a study of the effect of orientation of grain. Coarse-grained material may permit a study of the hardness of the individual grain along various axes.

The Report of the Hardness Testing Work of the A. S. M. E. presented by Major A. E. Bellis is as follows:

A. E. Bellis: When this paper was announced it was anticipated that an investigation which was being carried on by the A. S. M. E. Committee on Tool Research would be completed by this time. At a meeting of the Committee in New Haven last week it was reported that the work was not completed, but may be ready for publication and presentation at the December meeting of that Society.

This investigation is being carried on under the auspices of the A. S. M. E. by J. O. Keller of the State College of Pennsylvania. He is having the co-operation of several large tool manufacturers, the University of Cincinnati and two or three of the technical society committees.

His plan of work is this: A series of tools are being made from material of as uniform composition as possible, and through all the steps of the manufacturing and the machining of the tools, complete data is being kept of the physical properties, the structure or metallographic properties, the magnetic properties, different hardness tests, and it is planned to get detailed reports on the performance of these tools as well as dynamometer tests. It is the aim of this investigation to start with a few pieces, and get very complete data. It is hoped that this correlation of information will produce results which will be of use particularly to those of us who are interested in this subject of hardness testing and the practical significance of ''hardness.''

One of the lines of work which Mr. Keller has gone into most deeply has been the matter of finding out the significance of the Herbert hardness test, which was discussed at this symposium last year. He has made the statement that he believes the Herbert time test is closely related to the Brinell test, but this test has to be carried out under practically laboratory conditions to get consistent results. He intimates that the ''swing test'' gives a definite relation of the workability of the metal, more from the point of view of its deformation under pressure than from machinability under a tool.

I think mechanical engineers are beginning to appreciate that that term ''machinability'' is just as misleading along the lines of their investigations as the conceptions that were around the word ''hardness'' before we started this work. The A. S. M. E. have taken hold of the work of this Committee and have done a great deal in the way of educating mechanical engineers, not to talk about ''hardness,'' but to talk about a Brinell number or to always use a qualifying adjective with the term ''hardness.''

CHAIRMAN H. P. HOLLNAGEL: We will open the discussion by passing to the paper of S. C. Spalding on the ''Comparison of Brinell and Rockwell Hardness of Hardened High Speed Steel.''

A. E. BELLIS: What surface conditions were maintained in making the hardness tests in comparing the Rockwell and the Brinell tests; that is, what does the author recommend as to the conditions that should be met in a precise way.

S. C. SPALDING: The specimens were polished to a mirror surface, you might say, about the same kind of a surface you would use for a microscopic examination, and the diameter of the Brinell impression was taken with a microscope of 50 diameters; the Rockwell readings, of course, were read directly. The specimens were cut from the bars and the end that was tested was the end that had been cut off.

S. P. ROCKWELL: I wish to compliment Mr. Spalding on the work he has done. It is very interesting and I believe he has brought out some valuable data.

A. H. **D'ARCAMBAL**: I would like to ask Mr. Spalding if he does not believe that when high speed steel pieces are quenched from 2350 degrees Fahr. instead of 2300 degrees Fahr., the Rockwell reading on the 1100 degree Fahr. draw would probably approach the original Rockwell reading?

S. C. **SPALDING**: I am not prepared to say whether it would or would not. Of course, it approached it closely, the difference being slight, with perhaps only one point lower than the initial hardness. Whether it would have actually equalled or exceeded it with the higher quenching temperature, I would not want to say without further investigation.

A. E. **BELLIS**: I have in mind that a good deal of the published data on high speed steel shows higher Rockwell and Brinell readings after the draw than before. Was not Mr. Spalding's conclusion that this is not generally a fact, or is it safe to draw from this data the general conclusion that there is never a greater degree of hardness in high speed steel than the initial hardness?

S. C. **SPALDING**: That was just for my data. I have looked over the results of different investigators, and some of them find one and some find the other. The work done by Giltinan, published in the *Journal* of the American Steel Treaters Society, Volume 1, shows a curve on the high speed steel where the maximum secondary hardness occurs at 1000 degrees Fahr. Mr. Scott finds that it occurs at 1100 degrees Fahr.

Strauss and French last year published some work and they found that the point at which the maximum secondary hardness occurred varied with the hardening temperature. If hardened at 2300 degrees Fahr. they obtained a maximum secondary hardness at 1000 degrees Fahr., if hardened at 2150 degrees Fahr. the maximum secondary hardness varied from 950 to 1100 degrees Fahr., and at a 2415 degree Fahr. hardening temperature they obtained it at 1100.

I would not want anybody to draw any general conclusions from the data that I have here. I thing that this work should be taken as data that should be put in with various other data, and perhaps conclusions can be drawn which will mean something.

S. L. **HOYT**: Mr. Chairman, I want to make just a few remarks on the general relationship between a dynamic test and the static test, such as the relation between a Charpy impact test and a Brinell ball hardness test.

We had a paper at this convention by Dr. Moser of Germany, which related to a new method of interpreting Charpy impact test results. Those results to my mind are of sufficient importance to have them brought before the Society here, and I would like to take this opportunity to do it while the subject of impact tests is up. To be very brief, Dr. Moser has found that there are two material constants, as he calls them. One of these is the amount of work which is absorbed by a unit volume value of the deformed portion of the test specimen which is subjected to the impact. That is, each cubic centimeter absorbs a certain definite amount of work when being broken by the impact. The second constant is the velocity with which a strain may be propagated through a metal. That is a definite finite quantity and can be measured in meters per second.

So now in the case of some particular test we will say that the bar is broken at a certain definite velocity. The amount of energy which will be absorbed in breaking the bar will be a function of these two material constants. If the velocity of impact is lower than the velocity with which strains are propagated, then the material is enabled to absorb its full amount of energy, and in that case the energy is a simple function of the cross section of your test bar. If the striking velocity exceeds this velocity of propagation, only a comparatively small volume of metal is affected or enters into the resistance to impact, and the amount of energy absorbed in the impact is decidedly less than in the case of the slower striking velocity. So now any comparison between the dynamic test and the static test, in order to be strictly logical and correct, ought to take into consideration the effect of these two material constants, and particularly the velocity with which a strain is propagated.

Dr. Moser has shown that the reduction in area in the tensile test bears a direct relationship to the work-constant. It would be interesting to see if a simple relationship would hold between this constant and the results of the ball indentation test.

I. H. Cowdrey: I have not the figures in mind, but think that possibly the chairman may have. Can he give us an approximate idea of the relation of the speed of the blow under ordinary Charpy impact and this so-called propagation of the impulse through the material? Is it not true that as the Charpy tests are made, the velocity of the blow is way below the other?

S. L. Hoyt: I personally would much prefer referring any gentleman to the paper which I suppose will be published in the Transactions. It is all worked out there very nicely, but not in such form that I can give a direct reply to the question. Bearing in mind that it is the velocity of a plastic strain and not of an elastic impulse, I would say the two velocities mentioned are of the same order.

I. H. Cowdrey: I thought the velocity of propagation of the impulse in a steel rod was fairly rapid.

S. L. Hoyt: I am speaking of the plastic impulse.

I. H. Cowdrey: Is it so much lower than the elastic media?

S. L. Hoyt: I think from Dr. Moser's work it would be very materially lower. I will be very glad to give you the reference to that.

Chairman Hollnagel: Mr. Cowdrey are you not thinking of the velocity of sound in an elastic medium? In a device of the impact or rebound type, like the scleroscope, one probably has to think in terms of velocities of that order; in tests where deformation velocity is appreciable, I think it is quite of the order of magnitude of the velocity of impact. The two are quite different types of velocities.

A. H. d'Arcambal: The question was asked today about the preparation of the surface of the part to be tested by the Rockwell Machine. We find that the better prepared the surface, the higher the Rockwell reading. In other words, if you take a sample that has been hardened and barely clean the surface, you do not obtain as high a Rockwell reading as you do if you put a fairly good polish on the surface; it makes probably two or three points higher reading on the C. Scale.

I might add at this time that we have in our laboratory scleroscope, Brinell, Herbert and Rockwell Machine, and we find the Rockwell Machine the most satisfactory to use on hardened material.

Chairman Hollnagel: I think the point that has just been made on the question of polishing is a perfectly natural one, because, after all, polishing is but the plasticizing of the surface with the formation of an amorphous coat that materially hardens the surface of the material. I think this is generally understood as increasing the hardness number.

Member: I would like to say in reference to what Mr. d'Arcambal just said, that polishing should be differentiated. If they are going to use the Rockwell, they should not attempt to get the surface hardening; they should just clean the surface, certainly get off the scale. Planishing would naturally harden it. Just cleaning and polishing the surface certainly would not harden it and certainly would not give you the three points higher reading.

Chairman Hollnagel: If there are no other remarks, we will pass to the paper by Professor Cowdrey, "The Relation Between Rockwell and Brinell Hardness Scales."

S. P. Rockwell: I can appreciate Dr. Cowdrey has had some work in making up the formulæ from the tests he has made.

I was very much interested in the section he showed of a piece of brass and the large grain size. I want to bring out the point that all pieces which are tested with the Rockwell are not of such large grain size. We are principally steel men, and I think the Rockwell is used at present mostly on steel. The question as to what would happen if the Rockwell impression was made on one grain alone came up some time ago in relation to steel. Dr. Woodward of the Whitney Manufacturing Company took a piece of .04 to .08 per cent carbon steel and raised it to a high temperature so as to develop large grains. He then made a Rockwell impression with a sixteenth inch ball, cut vertically through the impression, polishing and etching. A photograph showed there are at least five crystals supporting the ball impression in one plane, and it was estimated that there are at least 20 crystals supporting the area of impression. We then repeated this operation with the diamond cone on high speed steel and found there are several thousand particles of carbides supporting the impression area.

W. D. Fuller: The brass industry has found that it is very beneficial to use a quarter inch ball for the Rockwell. Certainly no one grain, even of the coarsest brass, would be the only one tested with the machine under those conditions.

W. E. Titus: With reference to the Rockwell test, and about grain sizes, I want to differ from Mr. Rockwell on low carbon steel, on certain phases, not necessarily in all treatments. I have seen grains of a quenched and drawn carbon steel $\frac{3}{16}$ inch in diameter, single grains, which would extend completely through a one-sixteenth inch sheet. That material is not suitable material to use in a commercial purpose, in fact, it is usually a material made accidentally, but I think if we will investigate the difference in hardness of some of these ferrous grains, as well as the difference on non-ferrous brasses and other materials, we will find out some interesting things.

MEMBER: What pressures were used, Mr. Cowdrey?

I. H. COWDREY: I am very glad to answer that question, because it perhaps may also come a little bit into the discussion of the next paper. We used 500 kilogram pressures for the soft metals and 3,000 for the hard metals. We have found in our work in the laboratory that we could, generally speaking, check very closely with a given metal, regardless of whether we used 500 or 3,000 kilograms pressure. Taking an ordinary piece of steel and obtaining the hardness, with 500 or 3,000, we could generally check within one or two points on a steel that has a Brinell of 120. That is more or less along the discussion of the next paper, but I do not think the pressure between 500 and 3,000 kilograms will make enough difference in Brinell hardness for the practical man to bother his head about, from the experience that we have had in observations along that line. Theoretically, there may be a difference, because the elasticity of the ball will have an effect, but so far as practical results are concerned we have found that whether you use 500 or 3,000 that the hardness results in Brinell are practically the same, so I do not believe that this question would have a serious import. The proof of the pudding is in the eating, and that is what we got.

CHAIRMAN HOLLNAGEL: Are there any other remarks? In regard to the backing up of the grain that had four or five Rockwell marks on it, do you not suppose the containing effect of the metal itself which might be referred to as its hydrostatic pressure would account for some of the difference in the hardness that you have noticed?

I. H. COWDREY: I am not going to state any definite facts about that. I am purely guessing when it comes to that question of the hardness of different grains. That grain was fairly near the edge, and I am glad to say its longitudinal axis was parallel with the edge, so the distance from the edge would not have any effect.

CHAIRMAN HOLLNAGEL: I had in mind, it might not necessarily be the actual geometrical dimensions of the crystal itself, but its disposition to the immediate surroundings, i. e., how the slip planes lie with respect to the particular grain.

I. H. COWDREY: Possibly. That is, you feel it might be more perfectly reinforced at one end than the other.

CHAIRMAN HOLLNAGEL: Exactly. Are there any other questions or remarks on this paper before we pass to Dr. Hoyt's paper?

MEMBER: We can make two different tests, the Rockwell or the Brinell, but if we use the Rockwell test, we obtain a certain hardness. Then we know the depth of the indentation produced, we can compute the area of the indentation, we can compute the Brinell hardness from that; we could find it out. I wonder if the practical result here corresponds to the theory?

I. H. COWDREY: Absolutely no attempt was made to make that correlation. The results are entirely empirical. It was felt here that probably an equation obtained by plotting actual tests and fitting a mathematical equation to the actual results would be more satisfactory. Personally, I have every faith that your attack could be carried out and produce successful results. I believe that the Brinell hardness can be computed by taking the area of the Rockwell impression and carrying out exactly the same data. I have not tried it, but I believe it can be done.

S. P. ROCKWELL: That formula is not carried out with your relationship, but it is perfectly possible in using say a 100 kilogram load with the proper ball 1.83 mm. and measure the diameter of the impression, and apply to the conventional formula to find the Brinell number.

CHAIRMAN HOLLNAGEL: There is an additional objection to that; the deformed figure is never a portion of a perfect sphere because of the give of the material after the load has been removed. There is a restitution, the material springs back, causing a difference in the actual calculation based on the radius of that sphere, and the diameter of the sector, as compared to what is actually the case. This has been shown by Foss of the Cooper Institute at New York City in a paper presented about two or three years ago.

MEMBER: I was wondering what a comparison of these two formulas would give.

CHAIRMAN HOLLNAGEL: That is a good thing to investigate. It will not take long to take the figures of Mr. Cowdrey and calculate the actual figures on the basis of your suggestion.

MEMBER: Is there anyone of the speakers who has made experiments to know the influence of the time factor in making the Brinell test?

CHAIRMAN HOLLNAGEL: I believe in Dr. Hoyt's work that he calls attention to the fact that after 20 minutes of deformation on the Brinell machine there is a slight change in the two hardness numbers of about one or two, if I remember correctly.

S. L. HOYT: We tried that out on copper and one or two other metals, and after the first minute there isn't very much of a change in the impression diameter. The difference between thirty seconds and one minute is probably not enough to influence practical results. But for work such as I have described in my paper, it will be absolutely necessary to continue the loading beyond a minute, up to ten, fifteen or twenty minutes, which is necessary at the higher loads. I think I gave some actual figures showing the effect of the Brinell hardness number due to changing the time from thirty seconds up to ten minutes.

With manganese steel the situation is a little different. There is quite a measurable flow of metal, even after an hour in mangaense steel, but for most all other metals I think thirty seconds suffices for the Brinell test, but not for the constants a and n.

MEMBER: I believe I saw a publication around 1908 that mentioned that the Brinell number can vary ten per cent with the variation in time, and makes it very interesting to mention a very old definition of hardness, the French definition of Patell. He said, "Hardness is the ratio of the energy that produces a certain indentation to the volume of the indentation produced." In all the publications I have seen as yet, I have found no differerence, no variation in that hardness number. That would make very interesting the scleroscope tests in another line. Suppose, instead of taking 30 centimeters, of taking one foot for the height of the falling of the ball, we take it higher, we take, say, a loaded ball. We could not measure the indentation produced, but we can measure the energy of flow and the energy of rebound. We can measure the volume of the indentation.

There is another point. The time has no influence any more; the hardness does not vary during the test. In the Brinell test you deform your material in say two or three minutes. During this two or three minutes the hardness varies in itself.

Chairman Hollnagel: And because of the high velocity of propagation of the elastic wave compared with the indentation velocity. The energy is re-delivered to the ball. Yes, I think that is a very good idea, especially for the scleroscope instrument.

Does anyone else have anything to say on this particular paper? If not, let us pass on to a discussion of Dr. Hoyt's paper, "The Ball Indentation Hardness Test."

S. P. Rockwell: Dr. Hoyt, I have read your paper with a great deal of interest, and I believe it opens up great possibilities. I am going to do some work myself along your line and I hope the results are going to answer the questions why some forming steels act differently in forming operations, though having the same Brinell or Rockwell reading.

There are one or two questions I want to ask to clear my understanding. If you change your ball diameter, say to five millimeters, would not your volume for a and n be different? Would not your slope change slightly and would not your value change on the same piece of steel as when tested with a 10 mm. ball?

S. L. Hoyt: If you change the pressure in accordance with the formula which is given in the paper? Well, as a matter of fact, there is quite a series of relationships there between the constants a and n and the ball diameter, and they are all given in the paper here; so rather than take the time here, I would rather refer you to that, because it is a little complicated.

S. P. Rockwell: Supplanting the ball with the cone, you would still get on log log paper straight lines?

S. L. Hoyt: The ball test and the cone test really do not give the same kind of results for the reason that the cone gives an impression which is geometrically similar for all loads, whereas with the sphere the impressions are not geometrically similar.

S. P. Rockwell: Well, I have taken this. I have taken a piece of steel and obtained Rockwell readings at 150 kilograms, 100 kilograms and 60 kilograms with the diamond cone under the proper time element you mention until there was no more motion on the pointer on the Rockwell dial. I plotted out on log log paper the Rockwell number subtracted from 100. The results are straight lines from which I can figure a and n values. They, however, are entirely different from any a and n values given in your paper. I believe this would be natural.

S. L. Hoyt: That line has an a value to it, does it not?

S. P. Rockwell: Yes, it does.

S. L. HOYT: You see with a sphere the a value would have a little different meaning than it would with the cone; the a value with a sphere has a precise meaning, while with a cone it does not.

S. P. ROCKWELL: I obtained the information on the cone test,—from "Technology Paper, Bureau of Standards, No. 11," in which is plotted the values of cone tests, resulting in the straight line, that is, $P=at^n$ or $\log P=\log a+n \log t$.

S. L. HOYT: Meyers also, I think, gets the same thing.

S. P. ROCKWELL: I wanted to know whether or not I was right. It seems that your paper has answered several questions in regard to steel fabrication upon which I have been working along lines I have mentioned.

S. L. HOYT: With the cone test, though, there is this difference, that if you take as the depth of penetration the distance from the theoretical point of the cone to the top of the ridge of metal which comes up around the cone, and from that calculate the area of contact between your theoretical cone and your metal, you will find that the unit of load does not change with the indentation, and therefore that variation in unit load is eliminated as a variable in the cone test; whereas, it is a pronounced variable in the ball test. So there is that difference between the two tests.

S. P. ROCKWELL: It might interest you. For instance, on a piece of hardened tool steel I find an n value in the hardened state of 1:13, and an a value of 2.17, and in the annealed metal the n value is 1.28 and the a value 0.037.

S. L. HOYT: What happens to the n?

S. P. ROCKWELL: I do not know just now whether it goes up or down, but it is in line with your work, although the figures are different.

S. L. HOYT: Yes, of course, those figures are perfectly arbitrary, and as a matter of fact, the arithmetic of this paper is fairly arbitrary, too. You get different figures if you use different values of load.

A. HUNGLEMAN: I should like to ask, Professor Cowdrey, if you have included in your paper anything but annealed metals? I know from experience that a 500 load and a 3,000 load on Brinell will not give the same hardness relations in a partially cold worked metal, medium carbon steel.

S. L. HOYT: In the paper presented, materials were used in both cold worked and annealed conditions, and also under various conditions of heat treatment. It was shown that 500 and 1000 kilogram loads give different results because the higher load represents great work hardening.

I. H. COWDREY: I have suggested this in previous discussion here, but I would like to emphasize a little more than Dr. Hoyt did in Fig. 1, that considering this material, which is copper, a highly plastic material, using pressures from 1,000 kilograms to 3,000 kilograms, which is the maximum range under ordinary conditions, that the change in Brinell hardness due to change in pressure is only about one on the Brinell scale, which I think is as close as anybody would expect to check.

Another question I would like to ask for information. I am not familiar with the paper referred to here, but I wonder if Dr. Hoyt knows just how the gentleman obtained the yield point for copper. In testing copper I am usually up in the air when it comes to finding the yield point. How did the original paper, German, I think, obtain the yield point for copper? I have not read the paper, so can you tell me?

S. L. **Hoyt**: As I remember that paper, the yield point was taken as that point on the curve at which the deformation is twice as rapid as it is at the start. Of course, the yield point in copper is an indefinite thing.

I. H. **Cowdrey**: A little extension of Johnson's method; taking double instead of one and one-half. Thank you.

S. L. **Hoyt**: In respect to your first question, it is also pointed out in the paper here that the maximum on the Brinell hardness versus load curve will come at different loads depending upon the n values. We know for copper, though, that the curve is fairly flat, which accounts for your small change in hardness number, when there should be a larger change. The maximum itself depends upon the constant n, and we can be sure that at times we would not pick out the actual maximum Brinell hardness number for the purpose of a comparison such as yours.

I. H. **Cowdrey**: Perhaps that explains some of the discrepancies of the curves in my paper, Dr. Hoyt. Perhaps if we had gone at that a little better way, we might have drawn a little better curve between the Rockwell and the Brinell.

S. L. **Hoyt**: It has been pointed out that a great amount of work was done in the construction of your curve, but I think it would be interesting to re-examine your figures in the light of the Meyer analysis.

I. H. **Cowdrey**: That is a very good suggestion.

A. **Hungelmann**: Inasmuch as this n value seems to be the workability of the metal, I wonder if Professor Hoyt has examined the Herbert Machine in relation to that on the swing.

S. L. **Hoyt**: Well, I want to correct the impression, that n is not a function of the workability of the metal; n gives us the ability of the metal to be work-hardened by plastic deformation. Lead, for example, is a very plastic metal, but it has a low n value.

A. **Hungelmann**: Is there a relation between n, say, for steel or iron, and the Herbert Scale reading?

S. L. **Hoyt**: I should think there would be, if you consider the Herbert number, which depends upon the making of a path in the metal; I should think there would be, because a metal that hardens up on plastic deformation of the high n value would resist that more than one with a low n value.

Comment and Discussion

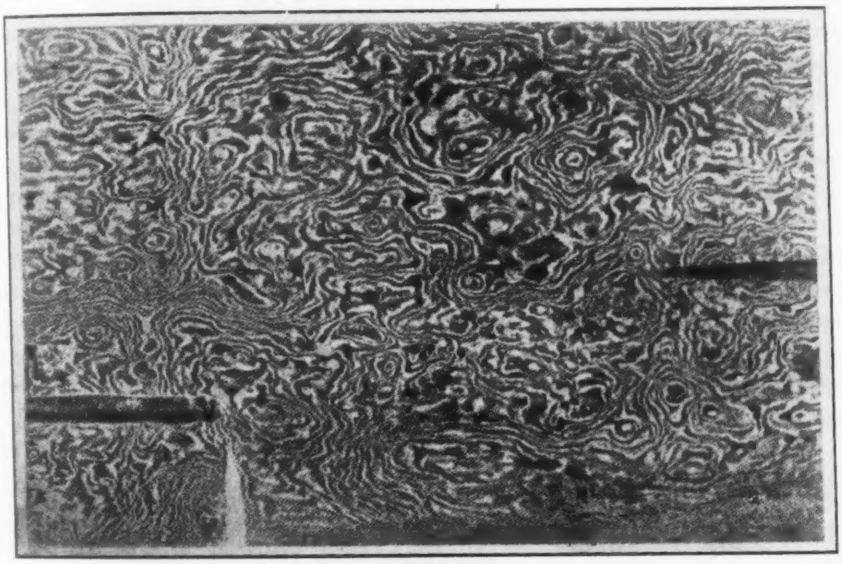
Papers and Articles Presented Before the Society and Published in Transactions Are Open to Comment and Criticism in This Column—Members Submitting Discussions Are Requested to give Their Names and Addresses

DISCUSSION OF V. O. HOMERBERG'S PAPER ENTITLED, "THE MACROSCOPIC EXAMINATION OF STEEL"[1]

By Col. N. T. Belaiew[2]

COLONEL Belaiew wrote to express his interest in the manner the subject of macrostructure of steel and, particularly, the question of fiber, was treated by the author.

Since 1907, when special experiments were conducted under the present writer's direction at the Poutilow works to study the various phenomena of crystallization of steel, he became aware of the paramount importance of the dendritic structure in castings and forgings and of the close connection between the original dendrite and the subsequent fiber. These ideas were embodied in all his subsequent writings and, particularly, in his recent paper on "Steel versus Lighter Alloys," read before the Institution of Aeronautical Engineers. Dwelling on the importance of the *correct* fibrous structure, the



Damascene Blade. 1x. From Professor Tschernoff's Collection.

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[1] This paper was published in the September, 1924, issue of *Transactions*, A. S. S. T.

[2] The author of this paper, Col. N. T. Belaiew, is consulting metallurgist, London.

present writer was drawing attention to two rather important points, which might also occur to the reader of Mr. Homerberg's paper.

The first point would be with reference to the failures due to the *crystallization* of steel (p. 307). The present writer most emphatically endorses the author's views on that subject. He would like, however, to make the observation, that every dendrite is a unit, both from the crystallographic and the chemical point of view.

The crystallographical unity of the dendrites is destroyed during the subsequent cooling by various processes occurring in the austenitic area, but the chemical non-homogeneity remains throughout the whole life history of the alloy, and in the cooled specimen is revealed by macroetching or contact printing. It is important to bear this dual side of the phenomenon in mind to understand why the fracture of any specimen at room temperature shows the ''grain'' and not the dendrite boundaries. Still the dendrites are there and proclaim their vitality by giving the ''fiber.''

As we have to reconcile ourselves to the existence of that fiber, our efforts, so it seems, ought to be directed towards using its occurrence intelligently, and that brings us to point two—that is to the right distribution of the fiber with reference to the shape and character of the specimen.

On pp. 303-309 the author (V. O. Homerberg) cites many instructive and interesting cases of fiber in reference to gears and crankshafts. The present writer would like to take this opportunity to ask the author and his readers to make a step further and to apply to present day problems the lessons to be derived from the structure of the damascene steel. In the accompanying picture the watering of a damascene blade from Prof. Tschernoff's collection is shown.

When discussing in 1918 Mr. Charpy's paper[3] the writer summarized the old experience of the Orientals saying that as the pattern changed from the usual parallel stripes to the motley, the mechanical qualities also experienced a parallel change, from the rather poor qualities of ''sham'' to the highest degree of excellence of the vertebrae. Therefore in his opinion our efforts ought to be directed towards a watering most suited to the article. He thinks that the problem, as stated, is still in its infancy, but will well repay investigation.

CONTRIBUTION TO THE DISCUSSION OF THE PAPER BY FRANCIS F. LUCAS ON ''THE MICRO-STRUCTURE OF AUSTENITE AND MARTENSITE.''

Colonel Belaiew (London) wrote to express his great interest in the paper by Mr. Lucas and his admiration of the beautiful photomicrographs of martensite. As one who has spent some considerable time in trying to work out a suitable method for preparing high power micrographs, the writer is particularly interested in following the progress of Mr. Lucas' work and would like to take this opportunity to congratulate the author most heartily on his achievement. He (the writer) thinks that some of the pictures will become classical and, eventually, will find their way into the text-books.

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[3] "Influence of Hot-Deformation on the Qualities of Steel," Belaiew on Charpy, *Journal*, Iron and Steel Institute, 1918, Vol. XCVIII, No. 2, page 35-37.

The Figs. 16 and 17, taken in conjunction with Fig. 7, make a special appeal to the present writer, as they furnish a splendid illustration of the very important, but yet not sufficiently appreciated fact, that the so-called acicular structure of martensite is a Widmanstatten structure, pure and simple. As far back as 1909 the present writer wrote his thesis on crystallization of steel on this subject as follows: ''Thus, the same law manifests itself in the chemical structure of the slowly cooled alloys and in the physical structure of hardened steel; it is the *octahedral crystallization of iron* which is brought into evidence to us in both cases.'' The material then available to the writer mainly consisted in the photographs of martensite and austenite by Osmond, where the octahedral sections were prominent; still the writer tried not to lose any opportunity to draw attention to the fact that four and not three directions were the general rule in the structure of martensite, just as in every other Widmanstatten structure. In the case of slowly cooled steels the present writer put together the typical Widmanstatten sections with those of the octahedron, and it is with the greatest interest that he studied the above named Figs. 7, 16 and 17 as furnishing analogous illustrations of the general section and the section of the cube, but now taken from martensitic grains.

The present writer finds himself also in complete accordance with the author on the question of the formation of martensite along the crystallographic planes of austenite, i. e., of gamma-iron. He thinks, however, that what the author really means by saying that ''the ultimate crystal form of austenite is the cube'' (p. 683) is, that austenite crystallizes in the ''cubic'' system and that a cube is the crystal unit of austenite. However, according to our present ''space-lattice'' nomenclature, it would be advisable to make a clear reference to the ''face-centered'' lattice of the gamma-iron. The more so, as one of the most important results of the author's paper seems to be to put a finishing touch to the internal structure of the austenitic gamma-grain.

Another point of extraordinary importance seems to be that of the small cubes on the Figs. 33, 34, 35 and 36. Here again the present writer finds himself in substantial agreement with the author. The author considers the tiny cubic forms to be ferrite and says that they are of the order of 1/100,000 inch. In micromillimeters that would bring them to about 250. Now, the present writer, being engaged since 1921 in the studies of cementite and ferrite in pearlite[1] under magnifications up to 400x, has come across some of crystalline micro-structures, which are quite in accordance with Mr. Lucas' observations. So, for instance, on Fig. 12 of the just cited paper[2], a section of pearlite under magnification of 3000x shows a number of small cubic etching pits on ferrite; these pits are of the same order of magnitude as those shown by Mr. Lucas, as their mean dimension (edge of the cube) is about

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[1] "The Inner Structure of the Pearlite Grain," *Journal* Iron and Steel Institute, 1922, No. 1, Vol. CV, pp. 202-227.

[2] Idem.

300 micromillimeters; moreover, tiny cubes of the same dimensions are scattered over some of the cementite lamellae. The striking analogy of these cubes on ferrite and of the cubes in austenite might be demonstrated by a comparison of Mr. Lucas' Fig. 36 and the just mentioned Fig. 12. In a special paper to be presented to the Royal Society the writer is dealing with another aspect of the question, but he would like to state here that these tiny cubes, as suggested in his paper by Mr. Lucas, are ferrite. It is interesting to add, that whilst the bloc of the writer's observations was made on ferrite, the first tiny cubes noted were those on the martensitic matrix of a damascene blade, which again is quite in accordance with Mr. Lucas' views.

NOTES FROM THE U. S. BUREAU OF STANDARDS

Correlation of Structural Conditions With Results of Notched Bar Tests of Metals

Single-blow and slow-bending notched bar tests of several metals and alloys rolled into flat plates and tested by the Bureau in its investigation of methods of notched bar testing, showed marked differences in results on specimens with the notch cut on the top or on the side of the plate. To explain the results, an extended metallographic study has been made of the specimens.

It is well known that the location of an impact test bar in relation to the direction of rolling, i. e., whether it is a longitudinal or a transverse bar, greatly affects the results, and that if both longitudinal and transverse bars are taken, the results throw much added light on the quality of the material. This series of specimens, all cut longitudinally, shows that the location of the notch on the top or side of a longitudinal specimen from a flat plate also throws much light on the directional properties of the material. The differences brought to light by the impact tests are shown to be directly connected with the number and type of inhomogeneities present, whether they be nonmetallic inclusions or essential metallographic constituents. From one point of view, the work shows that the type of alloy used, or the presence of inclusions or dirt may greatly affect the reliability of the material for engineering uses when the material is stressed in different directions. From another it shows that impact tests on suitable specimens can be used to give information to the engineer on these directional properties, and that for the proper interpretation of the results of impact tests the location of the notch in respect to directional inhomogeneities must be definitely known.

Many engineers question the real usefulness of impact testing because of alleged erratic results and the obscurity of the relation between test values and service. This work should be of value in showing a cause for results which appear erratic if superficially considered, but which, when correlated with the metallographic constitution of the material are not only not erratic, but throw valuable light on the usefulness of the material.

The Manufacture of "Malleable" Nickel and Nickel Alloys

In the manufacture of "malleable" products of nickel and certain nickel alloys,—such as forgings, rolled shapes, and castings,—rather unusual metallurgical treatments of the molten metal are resorted to in order that the cast product may be sufficiently malleable and ductile for the subsequent forging operations. The principal features of these treatments are the addition to the molten metal before casting, of small amounts of the metals magnesium and manganese. Nickel, without these additions, is not malleable either hot or cold, and will smash to pieces when hammered instead of squeezing out into the form desired.

Such "untreated" nickel, and nickel alloys are brittle because of the presence of tiny amounts of sulphur,—as little as one part of sulphur in

20,000 of nickel being sufficient to spoil the material. This sulphur comes from the ore which originally contains far more sulphur than it does nickel, all but this tiny remnant of sulphur being removed in the refining process. The sulphur is combined with the metallic nickel as a compound which collects in the form of thin and brittle films around the grains of nickel. This compound melts at a low temperature,—hence the cohesion between the nickel grains is impaired by the presence of these films, brittle when cold, and, of course, having no strength when melted, and the metal containing such films is brittle and unworkable either hot or cold.

In an investigation just completed under an Industrial Fellowship at the Bureau of Standards, maintained by the International Nickel Company, it has been found that manganese and magnesium react with this harmful compound of nickel and sulphur, taking the sulphur away from its combination with nickel, and making new compounds of the sulphur with the manganese or magnesium. The new compounds have a high melting point, and in addition take a form which affects the malleability but slightly. This form is made up of small particles uniformly distributed throughout the metal grains, instead of films in the metal mass.

INCREASING THE RESISTANCE TO WEAR OF GAGE STEEL

The generation of internal stress in gage steel on quenching has been studied theoretically and experimentally on one type of steel. This has a bearing on the prevention of cracking of gages on quenching and on wear resistance. Wear resistance appears to increase with quenching temperature, in this type of steel, so that if means can be found to avoid cracking when a high quenching temperature is used, the wear should be decreased.

PROGRESS IN INVESTIGATIONS OF ELECTROPLATING

During the month considerable progress has been made in connection with several electroplating investigations, as follows:

The study of nickel plating on zinc base die castings is practically completed, and the results are being complied for publication.

Work on the protective value of nickel plating on iron and steel has led to a better understanding of the factors which are likely to cause porosity of the coatings. Further work is in progress to determine whether by appropriate means this porosity can be decreased.

The study of nickel electrotyping has shown that the composition and properties of the graphite have a very important bearing on the time of covering with nickel. Further work will be required to define the desirable properties of the graphite.

Abstracts of Technical Articles

Brief Reviews of Publications of Interest to Metallurgists and Steel Treaters

THE EFFECT OF FREE SURFACES ON THE PLASTIC DEFORMATION OF CERTAIN METALS. **By F. C. Thompson and W. E. W. Millington, Manchester.**

This paper was presented at the September, 1924, meeting of the Iron and Steel Institute. Two previous papers have been published by these authors which deal with their views concerning the mechanism of the plastic deformation of those metals which crystallize in the face-centered and body-centered cubic lattices. In the present paper, the authors give reasons for believing that at the free surfaces of even an aggregate, the deformation will probably differ distinctly from that within the mass.

IMPROVEMENTS IN THE BRINELL TEST ON HARDENED STEEL, INCLUDING A NEW METHOD OF PRODUCING HARD STEEL BALLS. **By Axel Hultgren, Gothenburg.**

The above paper was presented at the September, 1924, meeting of the Iron and Steel Institute and describes a method of producing steel balls considerably harder than heretofore available, and therefore especially suitable for Brinell tests on hardened steel.

THE CHANGES OF VOLUME OF STEELS DURING HEAT TREATMENT. **By Leslie Aitchison and G. R. Woodvine, England.**

The above was presented at the September, 1924, meeting of the Iron and Steel Institute. In September, 1922, the authors presented a number of test results dealing with the dilatation and contraction or air-hardening nickel-chromium steels during various and special heat treatments. This paper deals with the extension of the series of tests previously recorded, which was primarily intended to investigate more particularly two points that had emerged during the initial series of experiments.

MAKING CAST MANGANESE STEEL. **By J. M. Quinn, in *Foundry*, December 15, 1925, page 964.**

The author tells how rapid melting and the proper method of making slag and alloy additions play an important part in producing satisfactory metal. He tells also how the steel is heat treated.

FURNACE INSTALLATION FOR HEATING NICKEL. **By George Ellerton, Jr., Tate-Jones & Co., Pittsburgh, in *Iron Age*, December 18, 1924, page 1595.**

This article describes a furnace installation wherein there are double-chamber oil-fired units for heating slabs for rolling and annealing. The automatic control is provided.

HIGH-FREQUENCY INDUCTIVE HEATING. By Dudley Wilcox, Ajax Electrothermic Corporation, Trenton, N. J., in *Iron Age*, December 18, 1924, page 1617.

The above article tells of an interesting application where sections of bars or rods must be heated to high temperatures in the electric furnace.

A ROLLER BENDING DIE FOR CHANNELS. By Earl Parsons, Parsons Speciality and Machine Company, in *Forging, Stamping and Heat Treating*, December, 1924, page 455.

The above tells how pieces are produced which are not marred in any way by the bending die. The material is plated and polished before the bending operation, which greatly reduces the cost.

ELECTRIC FURNACES FOR MEDIUM TEMPERATURES. By C. F. Cone, engineer, George J. Hagan Co., Pittsburgh, in *Forging, Stamping and Heat Treating*, December, 1924, page 467.

The above paper was presented at the 19th annual Convention of the A. I. and S. E. E., Pittsburgh, September, 1924, and explains how the electric furnace of the regenerative car type has eliminated many troubles in the preliminary annealing of wire used in the manufacture of horse-shoe nails.

CYANIDES AND CHEMICAL ENGINEERING. By H. G. Chickering, chemical engineer, duPont Company, in *Chemical and Metallurgical Engineering*, December 22, 1924, page 967.

The author of this article tells how the engineers of his company have worked out a process for producing cyanides by nitrogen fixation that is a splendid example of first class chemical engineering development.

ELECTRIC POWER AS A BYPRODUCT OF PROCESS STEAM GENERATION. By Theodore Maynz, consulting engineer, Cleveland, in *Chemical and Metallurgical Engineering*, January 5, 1925, page 5.

This article is a discussion of the different methods that may be used to accomplish this, the apparatus required and the relative costs.

ABSORBENT CARBONS FOR MANY INDUSTRIES. By Ralph H. McKee and Paul M. Horton, department of chemical engineering, Columbia University, New York City, in *Chemical and Metallurgical Engineering*, January 5, 1925, page 13.

The authors of this article give a review of the literature of this broad field and find that it reveals important properties of specified utility in many industrial applications.

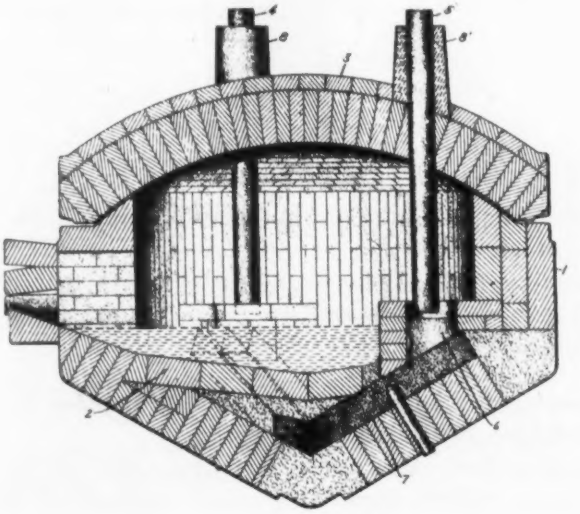
Reviews of Recent Patents

By

NELSON LITTELL, Patent Attorney
110 E. 42nd St., New York City
Member of A. S. S. T.

1,508,164, **Electric Furnace, Edgar F. Collins, of Schenectady, New York, assignor to General Electric Company, a corporation of New York.**

This patent claims the substitution of a refractory heat dissipating sleeve surrounding the electrode at its entrance to the electric furnace in lieu of the water-cooled chamber heretofore used for removing the heat from the electrode at this point. In the specific example given, the heat dissipating sleeve is composed of finely-divided carborundum, moulded together by a suitable binder. In the drawings, 3 designates the furnace roof, 4 and 5 the electrodes, and 8 and 8′ the refractory sleeves.

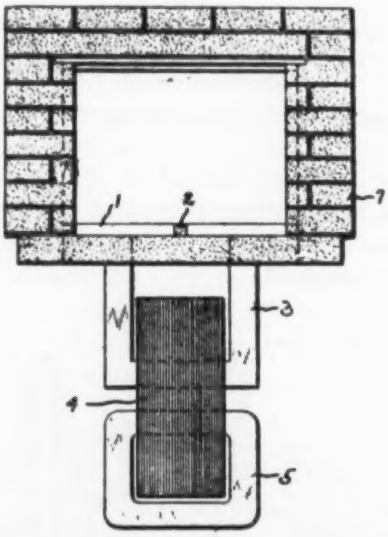


1,509,642, **Alloy, Richard Walter, of Duesseldorf, Germany.**

This invention relates to an improvement in high silicon iron alloys used especially for acid resisting and other chemical purposes, and which are normally too hard to be machined and so brittle as to often crack when accidentally struck in service. The inventor has discovered that by adding a small percentage of boron 0.03 per cent to 0.04 per cent to the high silicon alloy, the hardness of the alloy is materially reduced and it can be turned on a lathe, bored, drilled or otherwise machined. In view of the fact that the addition of boron to steel causes increased hardness in the metal, this discovery is quite significant.

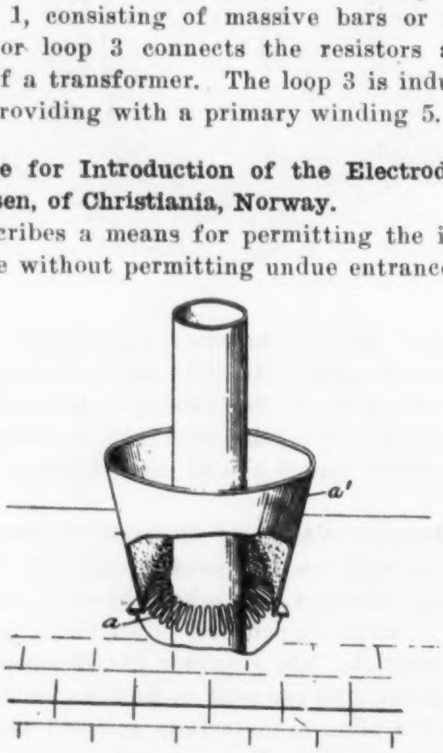
1,508,374, Electric Muffle Furnace, Irving R. Valentine, of Erie, Pennsylvania, **assignor to General Electric Company, a corporation** of New York.

This patent describes a muffle furnace, for use in heat-treating metals, etc. The furnace comprises the usual muffle housing 7, heated by means of electric resistors 1, consisting of massive bars or castings of iron or nickel. A conductor loop 3 connects the resistors and constitutes the secondary winding of a transformer. The loop 3 is inductively linked with a magnetic core 4, providing with a primary winding 5.



1,508,486, Device for Introduction of the Electrodes in Electric Furnaces, Filip Tharaldsen, of Christiania, Norway.

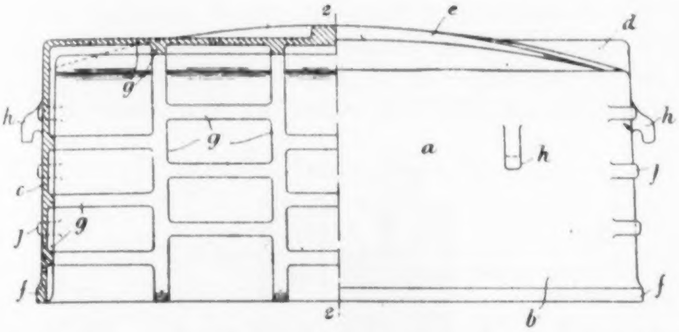
This patent describes a means for permitting the introduction of electrodes into a furnace without permitting undue entrance of air and thereby reducing oxidation in the furnace chamber. The device comprises a funnel *a′* surrounding the electrode opening, and one or more series of iron



rings *a* or of elastic sheet metal material at the bottom of the funnel, which is sufficiently flexible to permit sidewise movement of the electrodes during their introduction. The portions of the funnel above the rings *a* is packed with granular material, such as coal, or other carbonaceous material, which will protect the electrode and prevent the entrance of oxygen around the electrode. The rings *a* prevent the entrance of the granular material into the furnace.

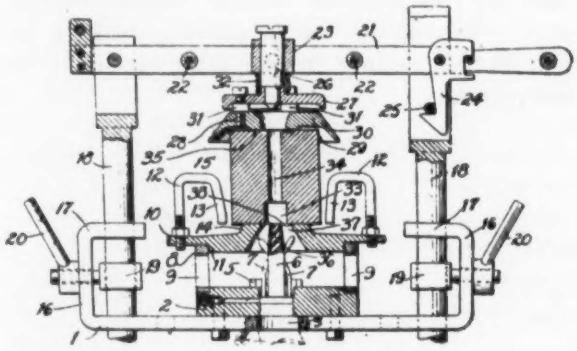
1,511,681, Annealing Cover, William Shaw, of Middlesbrough, England.

This invention relates to an annealing box or cover which is adapted to set upon a base plate and to cover the article to be annealed. The cover comprises a rectangular box "a" with sides "b" and "c" and top "d" integral. The usual trunnions or lifting lugs "h" are provided on the outside, and on the inside of the cover along the side walls and top, a network of reinforcing and strengthening ribs "g" is provided, and by casing ribs on the interior of the cover which is preferably formed of cast steel, the side walls are materially strengthened and the liability of buckling of the ribs is reduced because the temperature on the inside of the cover is approximately 100 degrees Cent. less than the temperature outside the cover.



1,513,974, Quenching Apparatus, Erik W. Ehn, of Canton, Ohio, assignor to the Timken Roller Bearing Company, of Canton, Ohio, a corporation of Ohio.

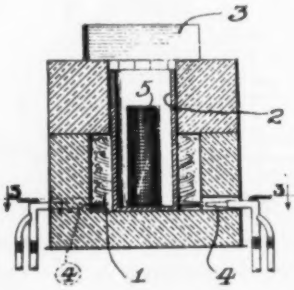
This patent discloses a quenching apparatus used to quench and harden



the interior and edges of an upsetting die, leaving the remainder thereof unhardened so as to be able to withstand shocks. The invention includes a base plate 2 having a hole 3 therein which communicates with a nozzle 4 for the quenching fluid, a nozzle 6 provided with spiral plates 36, gives a whirling effect to the quenching fluid which passes upward through the hole 37 in the plate 14 and into the bore 34 of the die 15, striking the lower edge of the die at 38 and whirling along the bore 34 to cool and harden the edge and interior of the die, while the outer surface is protected by means of the upper plate 30 from contact with the quenching fluid.

1,514,070, Heat Treatment of Iron, Alexander K. Schaap, of Brooklyn, **New York.**

This patent discloses the Schaap process of annealing cast iron which has been much discussed in the metallurgical literature during the past year. It is the object of the invention to provide a process of treating cast iron which will produce a malleable iron which can be distorted without fracture and which is free from hard spots. The process is preferably carried out in a gas-fired furnace 1 in which the flames from the nozzle 4 impinges upon the walls of the furnace so as to produce a whirling effect as illustrated. The material 5 to be treated, in this instance a column of piston rings, is enclosed with a wrought iron pot 2. The cover of the furnace is closed by means of fire bricks 3. It is essential that the pot 2 be of a non-porous material so as to exclude from the iron under treatment any deleterious gases. After packing the material 5 into the pot 2, the furnace is heated to raise the temperature of the cast iron to the Ac_1 point, whereupon the heat is shut off and the iron allowed to cool. The whole process for castings as large as one inch cross section can be carried out in a period not exceeding one hour, and differs mainly in the time element from the ordinary malleabilizing treatment.



News of the Chapters

STANDING OF THE CHAPTERS

In the January issue of TRANSACTIONS appeared the relative standing of the 29 chapters of the Society as of December 1, 1924. The tabulation which appears below shows the membership standing of the chapters on January 1, 1925. For the convenience of ready comparison, the list as published in January is included. It will be noted that there are several changes in Group I, only one change in Group II and several in Group III.

Standing as of December 1

I	II	III
1. Detroit (282)	1. Hartford (130)	1. New Haven (55)
2. Pittsburgh (274)	2. LEHIGH VALLEY (102)	2. Tri City (55)
3. Chicago (265)	3. Golden Gate (101)	3. Worcester (49)
4 Cleveland (249)	4. Syracuse (79)	4. Los Angeles (48)
5. Philadelphia (224)	5. Milwaukee (77)	5. Washington
6. Boston (219)	6. Cincinnati	6. Schenectady
7. New York (203)	7. Indianapolis	7. SPRINGFIELD
	8. Buffalo	8. South Bend
	9. Northwest	9. Rockford
	10. St. Louis	10. Rochester
		11. Providence
		12. Toronto

Standing as of January 1

I	II	III
1. Detroit (278)	1. Hartford (131)	1. TRI CITY (60)
2. CHICAGO (273)	2. Lehigh Valley (115)	2. New Haven (53)
3. CLEVELAND (267)	3. Golden Gate (103)	3. LOS ANGELES (53)
4. Pittsburgh (262)	4. Milwaukee (78)	4. ROCHESTER (53)
5. Philadelphia (247)	5. Syracuse (75)	5. Washington (49)
6. Boston (221)	6. Cincinnati	6. Worcester
7. New York (201)	7. Indianapolis	7. ROCKFORD
	8. Buffalo	8. Schenectady
	9. North West	9. South Bend
	10. St. Louis	10. Providence
		11. Springfield
		12. Toronto

The Cleveland chapter has made the greatest progress in Group I. Starting in 6th position in September, it has steadily advanced until now it is in third place, four members behind Chicago in 2nd place, and but 11 members behind Detroit in first place.

Another chapter that is showing progress and whose activities are being thought of with interest is Philadelphia, with a net gain of 13 members for December.

One of the most interesting developments in chapter activities as well as progress in membership is to be observed in the case of Rochester. In the report of December 1 it will be noted that they were occupying position 10 in Group III, while in the present report, they are holding position 4 and are tied with New Haven and Los Angeles in position 2 and 3.

BOSTON CHAPTER

THE Boston chapter of the American Society for Steel Treating held a meeting on January 22 in the Walker Memorial Hall at Massachusetts Institute of Technology. Supper was served at 6:30 p. m., which was followed by a brief discussion of "Troubles." This is a new proposition to try to make the meetings of greater value to the members of the chapter. Every member was asked to come prepared to submit at least one problem for general round table discussion after supper. Following this, the speaker of the evening, B. F. Shepherd, metallurgical engineer for Ingersoll Rand Co., Phillipsburg, N. J., was introduced and presented a most excellent paper on "Carburizing." Mr. Shepherd's paper was very interesting and exceptionally well presented, covering the field of carburizing in a general way. Much discussion was aroused. An attendance of 84 members and guests was present, and the evening proved to be instructive and enjoyable.

BUFFALO CHAPTER

The Buffalo chapter of the American Society for Steel Treating held a meeting at the Buffalo Athletic Club on January 16th, at which time the following motions were made, seconded and unanimously carried: That B. Clements of the Curtiss Aeroplane and Motor Corporation be appointed secretary-treasurer; that meetings be held every fourth Monday of the month; that G. J. Armstrong succeed M. A. Grossmann as chairman; that F. G. Brost be elected vice chairman, and David Bell as a member of the executive committee; that an advisory committee composed of W. H. Blocksidge, F. G. Brost and David Bell confer with G. J. Armstrong, on all general matters of policy pertaining to the activities of the chapter; that B. L. McCarthy of Wickwire Spencer Steel Corporation be appointed chairman of the Publicity Committee; that the next meeting of the chapter be held on Monday, January 26th at 8:00 p. m., (the usual dinner to be dispensed with); that O. W. Mueller of Brace-Mueller-Huntley, Inc., furnish the chairman and officers with a list of home and business addresses of the officers, and a list of members of the chapter. Also that Mr. McCarthy report to Mr. Armstrong regarding the possibility of securing a room for the next meeting of the chapter at the Hotel Buffalo, free of charge.

CHICAGO CHAPTER

The regular meeting of the Chicago chapter of the Society was held on January 8th at Orchestra Hall, at 8:30 p. m. The president of the University of Chicago extended an invitation to the members of the chapter to attend the lecture which was given by Professor Michelson on "Light Waves as Measuring Rods for Sounding the Infinite and the Infinitesimal."

The February meeting will be held on the 12th and will be addressed by W. S. Bidle, president; Zay Jeffries, treasurer, and W. H. Eisenman, secretary of the Society. Fred Grotz, metallurgist, Holt Manufacturing Co., Peoria, will speak at the March meeting on "Heat Treatment of Cast Iron." "Stainless Steel" will be the subject of T. H. Nelson, United Alloy Steel Corp., Canton, at the April meeting. Four reels of motion pictures, illustrating Einstein's Theory of Relativity, and a moving picture of "The Story of Alloy Steel," by the Interstate Iron and Steel Co., Chicago, will be shown at the May meeting of the chapter.

CLEVELAND CHAPTER

A special meeting of the Cleveland Chapter of the American Society for Steel Treating was held Friday evening, January 2, 1925, at Case School of Applied Science. The speaker on this occasion was Prof. W. Trinks, Professor of Mechanical Engineering at Carnegie Institute of Technology, Pittsburgh, and the title of the lecture was "Fuels and Furnaces." Prof. Trinks discussed his subject in an entertaining way, describing in detail the various fuels and furnaces used in the treatment of steel. This lecture was one in the night school course given under the direction of Prof. H. M. Boylston on "The Practical Heat Treatment of Steel," and members of the Cleveland Chapter received a special invitation to attend.

The regular January meeting of the Cleveland Chapter was held Friday evening, January 16, 1925, at 8:00 p. m. in the rooms of The Cleveland Engineering Society, Hotel Winton. Two members of the local chapter, W. P. Sykes and E. M. Slaughter, presented papers at this meeting. Mr. Sykes, metallurgical engineer, Cleveland Wire Division, General Electric Co., discussed the results obtained from tensile tests on steel wires of varying compositions and heat treatments at room temperatures and at liquid air temperatures. He also gave an interesting account of some work done with especially prepared iron. His paper was illustrated with diagrams and photomicrographs. Mr. Slaughter, assistant metallurgist, Bourne-Fuller Co., gave a practical talk on the heat treatment of cold-heading die, describing in detail a practical problem actually encountered in the shop, and the method used to overcome it. Considerable discussion followed the presentation of these papers. About 100 members were present at this meeting. Dinner was served in the hotel dining room preceding the meeting.

DETROIT CHAPTER

The Detroit chapter of the American Society for Steel Treating held a meeting on Monday, January 19th, in the General Motors Building.

"Corrosion Resisting Steels—Their Properties and Uses," was the subject discussed by the three speakers of the evening, namely, Dr. John A. Mathews, Crucible Steel Company of America; P. A. E. Armstrong, Ludlum Steel Company; and B. D. Saklatawalla, Vanadium Corporation of America. Dr. Mathews, well known for his extensive metallurgical research work, directed his remarks particularly to the comparative properties of corrosion resisting steels, with special reference to the higher chromium-nickel alloys. Mr. Armstrong, who has had wide experience both in the scientific and practical development of corrosion resisting alloys, is probably best known through the automobile industry for the development of a high grade valve steel. Mr. Saklatawalla, who has done much research work on the manufacture of these materials, described their manufacture direct from the ores. There was a large attendance at this meeting. Dinner was served at 6:30 p. m.

HARTFORD CHAPTER

The Hartford chapter of the American Society for Steel Treating held a meeting on Tuesday, January 13th, at 7:45 p. m. at the Engineer's Club, at which time A. H. d'Arcambal, metallurgist, Pratt and Whitney Co., delivered an address entitled, "Carbon and High Speed Steels Used in the Manufacture of Small Tools." His talk covered the composition and heat treatment of the various steels used for the manufacture of small tools, and was illustrated by lantern slides. He also had a collection of tools which showed the effects of improper steel, improper heat treatment and improper attention to the details of the machining, marking and grinding operations. An informal dinner was served at the University Club at 6:30 p. m.

INDIANAPOLIS CHAPTER

The Indianapolis chapter held its record meeting at the Y. M. C. A. auditorium on January 12th. Over 80 were present, and every one expressed the fact that it was the best meeting he had attended. Chas. Schemmel, salesman of Atkins Saw Company, accompanied by Mr. Komecke of the Y. M. C. A. gave a short snappy interesting musical program. Mr. Schemmel is a world wide known saw and violin player. The next event of the evening was an illustrated lecture given by D. M. Strickland, metallurgical engineer with the American Rolling Mill Co., Middletown, Ohio. Prof. Keller of Purdue University thanked Dr. Strickland for his fine lecture. Dinner was served at 6:30 p. m.

LEHIGH VALLEY CHAPTER

The Lehigh Valley Chapter of the Society held a meeting on Friday evening, January 9th, in the Exhibit Building of the Bethlehem Steel Company, at which time General T. C. Dickson, Commanding Officer, Watertown Arsenal, presented an illustrated paper on the "X-Ray Examination of

Metals,'' and Dr. F. C. Langenberg, Metallurgist of the Ordnance Department, U. S. Army, presented an illustrated paper on ''Recent Developments in the Manufacture of Cylindrical Forgings.'' General Dickson's paper covered the different phases of X-ray examination which were conducted under his direction at Watertown Arsenal. He first explained the usage and findings of a machine set-up to determine the angle of deflection of the different constituents of metal, by which its constitution can be examined. Another phase covered by General Dickson was the interesting work done in their X-ray department on internal defects. The Watertown Arsenal have not only photographed and recorded the defects not visible by the usual inspection, but have used this examination to determine their cause, and placed themselves in a position to recommend a remedy to prevent their reappearance.

Dr. Langenberg covered the development and theory of expanding a cylindrical forging by means of internal pressure which, through cold working, produces physical results comparable with those had the forging been heat treated. Dr. Langenberg presented his data in such a clear and concise way, that it was hard for the audience to realize the immense amount of work required to obtain the information that he presented.

This meeting was attended by 240 members of the Society and friends, and was the best attended meeting that the Lehigh Valley Chapter has ever had, not considering those held in conjunction with other Engineering Societies.

Through the courtesy of the Bethlehem Steel Company, the permanent exhibit was open for inspection that evening, and everybody who attended felt fully repaid, and the meeting was a success in spite of the abnormal weather. It was necessary to dig out the entrances of the building on account of a heavy snowfall.

LOS ANGELES CHAPTER

The Los Angeles chapter of the Society started the new year with a triangular meeting which was held in the conference room of the Westinghouse Electric and Manufacturing Company. Messrs. Bayley and Mears of the Pacific Abrasive Company arranged for the initial showing on the coast of the film entitled, ''Jewels of Industry,'' a two reel picture of the manufacture of carborundum, and its allied uses. The second part of the program was an address by Frank Carter, metallurgist at the General Petroleum Company, entitled, ''Practical Metallurgy as Applied to Heat Treatment.'' Mr. Carter was very descriptive and concise in his remarks, and was voted one of the first hand practical talks even given before the chapter on the above subject. The third event of the evening came with the introduction of Fred Offenhauser, superintendent of the Miller Engine Works. This company manufactures practically all the high speed motors for the present day auto racing classics. Mr. Offenhauser exhibited samples of parts ranging from pistons to axles and explained all particulars and questions asked him. There was a record attendance at this meeting.

NEW YORK CHAPTER

On Wednesday, January 21st, the New York chapter of the American Society for Steel Treating held a meeting in the assembly room of the Merchants' Association of New York, Woolworth Building. "Automotive Steels and Automobile Design," was the title of the address given by T. H. Wickenden, who is connected with the development and research department of the International Nickel Co., New York.

NORTH WEST CHAPTER

On Tuesday, January 20th, the North West chapter of the Society held a meeting at the Manufacturers' Club of Minneapolis, at which time George Rose, the Chicago service engineer of the Oxweld Acetylene Company, delivered an address entitled, "Oxyacetylene Welding." He also presented the company's new film entitled, "Oxwelding and Cutting the Universal Tool of all Industry," which shows the latest development and the most modern practice in the art.

PHILADELPHIA CHAPTER

The Philadelphia chapter of the American Society for Steel Treating postponed its regular December meeting one week due to the Christmas holidays. Consequently, on Friday evening, January 2nd, the loyal gathered together in the Engineers Club. We use the above phrase because on this night the worst snow storm of the season was in full swing, making it difficult to get anywhere. This cut down the attendance considerably, there being about 20 for dinner and 60 for the meeting. The trains from Washington and Bethlehem finally arrived, however, so R. L. Sanford, physicist of the Bureau of Standards, gave a very fine talk on the "Fundamental Principles of Magnetic Analysis," which was well received and aroused a lively discussion.

The second part of the program consisted of two talks, both by G. A. Richardson, chief of the technical publicity bureau, Bethlehem Steel Company. His first talk was on "Mayari Iron," its characteristics, properties and applications. He illustrated his remarks with lantern slides. The other feature was a motion picture, showing the method of coke manufacture at the Johnstown, Pa., plant of the Bethlehem Steel Company, which was interesting in its newness and the large equipment used.

The Library committee of the chapter under the able leadership of Theodore Wiedemann has purchased nearly 50 volumes on Metallurgy and Heat Treatment. They have been installed in a special place in the Temple University Library for the benefit of the chapter students of metallography and heat treatment, and any of the membership so desiring.

Beginning with the next meeting, January 30th, there will be a news sheet mailed out with every meeting notice. This sheet will contain the names of all new members, applications for membership as well as a list of those desiring positions and a list of positions open. Should individuals or firms outside of the Philadelphia chapter desire to avail themselves of this privilege, we shall be glad to take care of it without charge.

COURSE IN HEAT TREATMENT AND METALLOGRAPHY GIVEN BY PHILADELPHIA CHAPTER

In the fall of 1921, J. J. Crowe, then chapter chairman, aided by D. K. Bullens, A. W. F. Green, A. H. Collins, Dr. W. M. Mitchell, and others, at the instance of the executive committee and members of the chapter, instituted an evening course as an aid to the practical steel treaters of Philadelphia who wished to broaden their knowledge. Hearty cooperation was received from Temple University, which generously equipped a laboratory and provided a lecture room for the work.

In the Spring of 1924 Mr. Crowe, who had directed the course for three years, moved away from Philadelphia, and the work was turned over to Horace C. Knerr, and a more complete program was inaugurated. Additional laboratory equipment was secured and the list of special lecturers extended.

The 1924-1925 season opened on October 6th with an enrollment of ninety students, 55 of whom were taking both lecture and laboratory work—striking evidence of the real demand for educational work of this nature, once it is brought to the attention of those who can benefit by it.

The course covers thirty weeks, and includes one lecture period and two laboratory periods each week. It is arranged so that the lecture course is complete in itself, and may be taken without the laboratory work by those who so desire, such as executives, engineers, salesmen, purchasing agents, chemists, foremen and others to whom the laboratory work is not essential. It is noteworthy that nearly two-thirds of those enrolled are taking the laboratory work as well as the lectures.

Following is a partial list of the equipment now available:

Two modern Bausch and Lomb inverted microscopes, with facilities for making photo-micrographs; dark room; Sauveur polishing machine; Leeds and Northrup Pyrometers and ''Hump Method'' electric furnace; American gas furnace with accessory equipment; Brown Instrument Company pyrometer and automatic temperature controller, Wilson-Mauelen pyrometer, Olsen Brinell Hardness Testing Machine; Rockwell Hardness Tester; Shore Scleroscope, etc.

Lectures covering the regular subject matter of the course, in logical sequence, are given by Mr. Knerr. Supplementary lectures are given at frequent intervals by men who are recognized authorities in special fields, thus affording the students a very broad outlook. The staff of lecturers and instructors is as follows:

Dr. James H. Dunham, Dean, College of Liberal Arts and Sciences, Temple University.

Horace C. Knerr, Director of Course in the Heat Treatment and Metallography of Steel. Chief Metallurgist, Naval Aircraft Factory, United States Navy Yard, Philadelphia.

Professor Bradley Stoughton, in charge of Department of Metallurgy, Lehigh University.

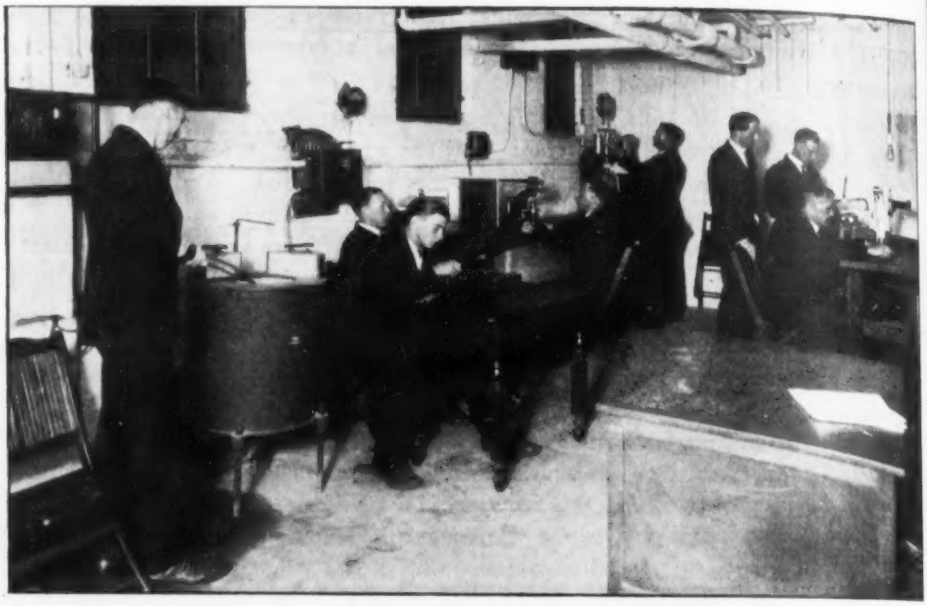
Dr. George L. Kelley, Chief Metallurgist, Edwin G. Budd Manufacturing Co. and Budd Wheel Co.

Dr. Walter M. Mitchell, Research Metallurgist, E. I. duPont de Nemours & Co.

John J. Crowe, Engineer in Charge, Apparatus Research & Development, Air Reduction Co.

Arthur W. F. Green, Metallurgist, John Illingworth Steel Co., Philadelphia.

Dennison K. Bullens, Consulting Metallurgist.



A Corner in One of the Laboratories.

Arthur L. Collins, Sales Metallurgist, Horace T. Potts & Co.

Joseph E. Chapin, Chief Chemist, United States Navy Yard, Philadelphia.

Laboratory Instructors

Russell M. Berry, Chemist, Smith, Rudy & Co., Philadelphia.

Mathew M. Kennedy, Metallurgist, Navy Yard, Philadelphia.

T. Watson Downes, Assistant Metallurgist, Naval Aircraft Factory.

John B. Claffey, Assistant Metallurgist, Westinghouse Electric and Manufacturing Co., South Philadelphia Works.

Scholarships

This year the scholarship committee awarded 15 scholarships. This was made possible through the generosity and exceptional interest taken in this course by the following firms and individuals: The E. F. Houghton Company, 2 scholarships; Charles E. Carpenter, 1; The Brown Instrument Company, 2; Leeds and Northrup Company, 2; Ajax Electro-Thermic Corporation through its president, G. H. Clamer, 1; John P. Brown, general manager, Ace Hardware Company, 1; Theodore Wiedemann, president Wiedemann Machine Company, 1; Professor Bradley Stoughton, 1; The National Office A. S. S. T., 1;

The Philadelphia chapter, 1; Horace T. Potts and Company, 1; Anonymous, 1.

Through the co-operation of Temple University, the lecturers and laboratory instructors, the enrollment fee has been maintained at a very low figure, just sufficient to cover necessary expenses.

The attendance of the class has been excellent during the first half of the year, which is gratifying evidence of a sustained interest.

The following gives an outline of the course in heat treatment and metallography of steel as given by the Philadelphia chapter.

I. INTRODUCTORY.
  1. An Ancient Craft and a Modern Science.
  2. Physical Metallurgy.
  3. Principles of Chemistry and Physics.
  4. Physical Properties of Steel.

II. MANUFACTURE OF IRON AND STEEL.
  1. Processes of Manufacture:
    (a) Ores and Materials.
    (b) Pig Iron.
    (c) Wrought Iron.
    (d) Crucible Steel.
    (e) Bessemer.
    (f) Open Hearth.
    (g) Electric.
    (h) Miscellaneous.
  2. Mechanical Treatment:
    (a) Hot Working.
    (b) Cold Working.

III. METALLOGRAPHY.
  1. Microscopic Examination of Metals:
    (a) The Metallurgical Microscope.
    (b) Preparation of Specimens, Polishing, Etching.
    (c) Photomicrography.
  2. Macroscopic Examination:
    (a) Deep Etching.
    (b) Sulphur Printing.
    (c) Flaws.
    (d) Segregations.
  3. Structure of Metals:
    (a) Pure Metals.
    (b) Alloys.
    (c) Wrought Iron.
    (d) Steel, Low, Medium and High Carbon.
    (e) Cast Iron, etc.
    (f) Alloy Steels.
    (g) Impurities.
  4. Micro-Constituents of Steel:
    (a) Ferrite.
    (b) Cementite.
    (c) Pearlite.
    (d) Austenite.
    (e) Martensite.
    (f) Troostite.
    (g) Sorbite.
  5. Critical Points of Steel—Their Manifestations.
  6. Hot and Cold Working.

IV. PYROMETRY.
  1. Heat and Temperature.
  2. Methods of Measuring Temperature:
    (a) Melting, Freezing, Boiling Point.
    (b) Expansion.
    (c) Electrical Resistance.
    (d) Thermo-electric.
    (e) Optical.
    (f) Radiation.
  3. Thermocouples.
  4. Galvanometers and Millivoltmeters.
  5. Potentiometers.
  6. Calibration.
  7. Temperature Recorders.
  8. General Precautions.

V. THERMAL ANALYSIS.
  1. Methods of Determining Critical Points.
  2. Heating and Cooling Curves:
    (a) Time-Temperature Curves.
    (b) Inverse Rate Curves.
    (c) Different Curves.

VI. THEORY OF HARDENING.
  1. Nature of Critical Points.
  2. Slip Interference Theory.
  3. Constitution Diagrams.

VII. HEAT TREATMENT.
  1. Purposes of Heat Treatment:
    (a) Tool Steels.
    (b) Structural Steels.
  2. Annealing, Normalizing.
  3. Hardening, Tempering.
  4. Carburizing, Case Hardening.
  5. Alloy Steels:
    (a) Effects of Alloys.
    (b) Treatment.
  6. High-Speed Steel.
  7. Equipment Used in Heat Treatment:
    (a) Fuels.
    (b) Furnaces.
    (c) Quenching Equipment.
    (d) Pyrometers.
    (e) Temperature and Atmospheric Control.
  8. Miscellaneous and Special Treatments.

VIII. INSPECTION AND TESTING.
  1. Chemical Analysis.
  2. Physical Testing:
    (a) Tensile Tests — Tensile Strength, Yield Point, Proportional Limit, Elongation, Reduction of Area; Modulus of Elasticity.
    (b) Hardness Tests, Brinell, Shore Scleroscope, Rockwell Hardness Tester, etc.
    (c) Impact Tests, Charpy, Izod, etc.
    (d) Fatigue Tests.
    (e) Magnetic Testing.
    (f) X-Ray Examination.
  3. Metallographic Inspection.
  4. Inspection During Fabrication.
  5. Specifications.

PITTSBURGH CHAPTER

The January meeting of the Pittsburgh Chapter of the Society was held on the evening of the 6th in the Crystal Room of the William Penn Hotel. The U. S. Bureau of Mines motion picture depicting, "The Story of Alloy. Steel," was shown and proved to be of great interest. The speaker of the evening, A. H. d'Arcambal of the Pratt and Whitney Company of Hartford, was welcomed by Duray Smith, the chairman of the Pittsburgh chapter, as no formal introduction was necessary to Mr. d'Arcambal's host of Pittsburgh friends and fellow society members. He chose the subject, "Carbon Tool and High Speed Steels Used in the Manufacture of Small Tools," for his talk. Mr. d'Arcambal first exhibited numerous specimens of taps, threading dies, reamers, hobs, milling-cutters, etc., giving the chemical analysis of each kind of tools and the required heat treatment. He said that both electric furnace and crucible steel were used in the manufacture of tools, though electric furnace steel has been used more extensively since the war. Among the carbon tool steels used, he told of hardening gage blocks, which were approximately 1.50 per cent chromium and 1.25 per cent carbon. and their subsequent seasoning in order that they might retain their exact size to within a few millionths of an inch. For keen-edged cutting tools, he gave the analysis: 1.25 per cent carbon, 0.40 per cent silicon, and 0.25 per cent chromium. An interesting notation here was that the chromium prevented the precipitation of graphite. In general, for tools which must resist shock, the analysis was about: 1.20 per cent carbon and 0.15-0.20 per cent vanadium, though for punches the carbon was lowered to 1.00 per cent with the same vanadium. Of interest to heat treaters was the mentioning of the narrow range, namely, 1410-1430 degrees Fahr. for 0.90 per cent carbon and 1.70 per cent manganese steel, but when the same steel had been treated with about 0.25 per cent vanadium, the hardening range was enlarged to 1420-1500 degrees Fahr. In describing high speed steels, Mr. d'Arcambal confined himself largely to those of high tungsten-low vanadium and of low tungsten-high vanadium, though he mentioned that cobalt high speed steel seemed to be better for lathe tools than for hobs, cutters, etc., which were not ground much after hardening. He then showed some slides of various microscopic conditions calling attention to the structures which could best be used for tool making and those which could not. Graphs of hardness tests for different quenching and tempering temperatures of tool steels were shown. Another interesting series of slides showed the microstructure of high speed steel after oil-quenching without and with the usual temper as compared with the use of the lead bath. It was also demonstrated that the proper hardening temperature is most important.

After the slides had been shown, specimens of grinding cracks were passed around and commented upon, especially as to their cause. Several cleverly color-drawn specimens were exhibited which brought forth some amusing remarks and incidents from some of the old-timers.

A general discussion ensued and the speaker was called upon many times to explain away some tool kinks. That the Pittsburgh chapter appreciated Mr. d'Arcambal's talk was amply demonstrated by the large attendance and the freedom of the discussion.

RHODE ISLAND CHAPTER

The regular January meeting of the Rhode Island chapter of the American Society for Steel Treating held on the 16th in the rooms of Providence Engineering Society, was addressed by Dr. Robert S. Williams, professor of metallurgy and analytical chemistry, Massachusetts Institute of Technology. The subject of his illustrated paper was ''The Influence of the Various Structural and Chemical Constituents on the Physical Properties of Steel,'' and was of exceptional interest not only to steel treaters but machine shop men, as it afforded them the opportunity of obtaining much practical information concerning the materials they are constantly using.

SOUTH BEND CHAPTER

On Tuesday evening, December 30th, the South Bend chapter of the American Society for Steel Treating held a meeting at which time a film entitled, ''Oxyacetylene Welding and Cutting, the Universal Tool of all Industries,'' was presented by the Linde Air Products Company. This picture was presented by a representative of the company.

The chapter held a meeting on January 27th at the Oliver Hotel at 8:00 p. m. The president of the Society, W. S. Bidle and, secretary, W. H. Eisenman, were in attendance at this meeting, Mr. Bidle choosing for his subject ''Most Important Things in Heat Treating.'' Mr. Eiseman spoke of the activities and phenomenal growth of the Society in the last few years. Dinner was served at 7:00 p. m.

SPRINGFIELD CHAPTER

The regular monthly meeting of the Springfield chapter of the American Society for Steel Treating was held on Tuesday, January 20th, at 8:00 p. m. in the Chamber of Commerce rooms. A. H. d'Arcambal, metallurgist at the Pratt and Whitney Company of Hartford, presented a paper entitled, "Heat Treatment of Carbon Tool and High Speed Steel. This was illustrated with lantern slides and by a collection of tools showing the effects of improper steel, improper heat treatment and improper attention to the details of the machining, marking and grinding operations.

SYRACUSE CHAPTER

On Monday, January 19th, the Syracuse chapter of the Society held a meeting at which time A. H. Kingsbury, Crucible Steel Company of America, delivered an address entitled, ''Tool Steel.'' At the February 16th meeting ''Die Castings'' will be the subject of the paper to be presented by Sam Tour, of the Doehler Die Casting Co., Batavia, N. Y. On March 16th, Major A. E. Bellis, of the Bellis Heat Treating Co., New Haven, will speak on ''Salt Bath Heating.'' J. M. Watson, Hupp Motor Car Corp., will show his film, ''The Heat Treatment of Automobile Parts,'' on Monday, April 20th.

ADDRESSES OF NEW MEMBERS OF THE AMERICAN SOCIETY FOR STEEL TREATING

EXPLANATION OF ABBREVIATIONS. **M represents Member; A represents Associate Member; S represents Sustaining Member; J represents Junior Member; and Sb represents Subscribing Member.** The figure following the letter shows the month in which the membership became effective.

NEW MEMBERS

Adelson, J. A., (M-12), assistant metallurgical engineer, Elyria Iron and Steel Co.; *mail* 232 East 131st Street, Cleveland.

Alexander, A. H., (A-11), Canadian agent for Rockwell Direct Reading Hardness Tester; *mail* 203 Manning Chambers, 72 Queen St., West, Toronto.

Becket, F. M., (M-12), chief chemist, Electro Metallurgical Co., and vice-president, Union Carbide Co.; *mail* Room 1801-30 East 42nd St., New York City.

Beler, R. J., (M-11), treasurer, Cowles Tool Co.; *mail* 2086 West 110th St., Cleveland.

Bissett, G., (A-12), general manager, Bissett Steel Co.; *mail* 1255 Marquette Road, Cleveland.

Blazek, J. Y., (M-12), secretary, Lake Erie Metal Products Co.; *mail* 4257 East 128th St., Cleveland.

Bolkovitinoff, N. F., (M-10), Ostojenka 1st Zatchatievsky, 15, 3, Moscow, Russia.

Cannon, R. W., (Jr-12), student, University of Michigan, Ann Arbor, Mich.; *mail* 204 Waverly Ave., Syracuse, N. Y.

Carrecabe, J. A., (M-11), manager, John M. Carrecabe, Inc., Chelsea, Mass.; *mail* 50 Warwick Road, Melrose Highlands, Mass.

Chang, K. M., (Jr-11), student, Massachusetts Institute of Tech., Box 132, Cambridge, Mass.

Clark, W. B., (M-12), machinist, Apex Machine Co.; *mail* 1716 North 22nd St., Philadelphia.

Clement, W. J., (M-10), engineer, Bossert Corp., Utica, N. Y.

Cook, R. M., (S-11), Boston Pressed Metal Co., 171 Union St., Worcester, Mass.

Day, R. O., (Jr-12), senior student of metallurgy, Missouri School of Mines; *mail* Box 724, Rolla, Mo.

Diemer, C. P., (M-12), Champion Rivet Co., Harvard and East 108th St., Cleveland.

Donkin, W. T., (M-12), Cleveland Wire Spring Co., East 38th and Hamilton, Cleveland.

Dore, F. F., (M-12), chief chemist, American Steel Foundries, Alliance, Ohio.

Fallon, C. G., (A-9), New England representative, 141 Milk St., Boston.

Fielding, John, (M-12), instructor of mechanical engineering, State University of Iowa, Iowa City, Iowa; *mail* R. F. D. No. 9, Iowa City, Iowa.

France, Thomas, (M-12), inspector, Oakes Co.; *mail* 806 East 16th St., Indianapolis, Ind.

Fromen, A. W., (M-11), superintendent, Manufacturers Tool and Die Co.; *mail* 269 Seneca Parkway, Rochester, N. Y.

Gates, W. H., Jr., (S-11), production manager, Baldwin Chain and Mfg. Co.; *mail* 199 Chandler St., Worcester, Mass.

Gayley, S. A., (Jr-12), student, Massachusetts Institute of Technology, Cambridge, Mass.; *mail* 1768 Beacon St., Brookline, Mass.

Gorman, Wm., (M-10), tool maker, Link Belt Co.; *mail* 3812 East New York St., Indianapolis, Ind.

Grant, F. W., (M-12), foreman, Llewellyn Iron Works, Los Angeles; *mail* 182nd St., Gardena, Calif.

Greger, G. W., (M-11), foreman, band saw hardening department, Henry Disston and Sons; *mail* 5010 Jackson St., Frankford, Philadelphia.

Hartzell, Daniel, (M-9), foreman, forge shop, Hudson Coal Co.; *mail* 437 East Market St., Scranton, Pa.

Hathorn, J. G., (M-12), chemist, American Steel Foundries, Pittsburgh.

Heil, C. A., (A-12), sales manager, Carpenter Steel Co., Cleveland.

Herbst, R. H., (M-12), electric furnace melter, Kinite Co.; *mail* 200 14th St., Milwaukee.

Herman, Richard, (M-11), foreman, Cochran Bly Co.; *mail* 15 St. James St., Rochester, N. Y.

Hermanson, A. J., (M-11), chemist, A. Schrader's Son, Inc., Brooklyn, N. Y.

Hirsch, L. F., (M-11), member of firm, Philadelphia Rust Proof Co.; *mail* 1127 Rockland St., Philadelphia.

Hyde, Wm., (M-6), assistant foreman, Royal Typewriter Co.; *mail* 80 New Britain Ave., Hartford.

International Harvester Co., (S-12), engineering and experimental department, 606 South Michigan Ave., Chicago.

Johnson, J. I., (M-12), foreman, hardening department, Peck Stow and Wilcox Co.; *mail* 101 North Main St., Southington, Conn.

Kauffman, J. R., (A-11), salesman, Henry Disston and Son, Inc., Philadelphia.

Koepke, C. A., (M-6), 617½ Tremont St., Laramie, Wyoming.

Knight, H. N., (M-12), chemical laboratory, Henry Disston and Son, Inc., Philadelphia; *mail* 5415 Tacony St., Bridesburg, Pa.

Li, C. H., (Jr-9), student, Massachusetts Institute of Tech.; *mail* Box 239, Cambridge, Mass.

Lohman, Charles, (M-12), heat treater, Bryden Horse Shoe Works; *mail* R. F. D. No. 1, Allentown, Pa.

Lyon, G. A., (M-12), engineer, Metal Stamping Co., Long Island City, N. Y.

Mathews, Frank, (M-11), assistant foreman, forge shop, U. S. Steel Corp.; *mail* R. F. D. No. 1, Box 71, Homestead, Pa.

Mauerman, George, (M-11), foreman, North East Electric Co.; *mail* 202 Lehigh Ave., Rochester, N. Y.

McClelland, B. C., (A-12), tool supervisor, U. S. Gauge Co.; *mail* 519 Market St., Perkasie, Pa.

McCully, F. D., (M-12), Pennsylvania Railroad Co.; *mail* 1939 Fairmount Ave., Philadelphia.

McGrath, Thos., (Jr-12), student, vocational training, Temple University, Philadelphia; *mail* 207 Cove Road, Merchantville, N. J.

McMurrich, J. R., (M-12), heat treating department, Canadian Acme Screw and Gear Co.; *mail* 75 Forest Hill Road, Toronto, Ontario, Canada.

Miller, B. K., (Jr-12), student, University of Pittsburgh, Pittsburgh; *mail* 722 Florence Ave., Avalon, Pa.

Murray, C. B., (M-12), partner, Crowell and Murray Co., 406 Perry Payne Bldg., Cleveland.

Nix, F. C., (Jr-12), student, Missouri School of Mines; *mail* Box 412, Rolla, Missouri.

Pollak, Joseph, (M-11), president, Joseph Pollak Tool and Stamping Co.; *mail* 81 Freeport St., Dorchester, Mass.

Prentiss, C. E., (M-11), foreman, spring department, American Steel and Wire Co., Waukegan, Ill.

Primrose, J. S. G., (M-11), metallurgist, Richard Johnson & Nephew, Ltd.; *mail* Bradford Iron Works, Manchester, England.

Reese, D. J., (Jr-12), student, University of Michigan; *mail* 1824 Geddes Ave., Ann Arbor, Mich.

Roe, G. W., (M-12), inspector, Robert W. Hunt Co.; *mail* 547 Stuyvesant Ave., Rutherford, N. J.

Rossier, L. J., (M-12), hardener, Barber-Colman Co.; *mail* 1419 Peach St., Rockford, Ill.

Rudolf, Charles, (M-11), foreman, Bastian Bros. Co.; *mail* 276 Mount Vernon Ave., Rochester, N. Y.

Schuck, H. L., (M-11), engineer, Wood and Spencer Co.; *mail* 1930 East 61st St., Cleveland.

Shapiro, C. H., (M-9), associate metallurgist, U. S. Bureau of Mines, Bartlesville, Okla.; *mail* 1520 Lowell Blvd., Denver, Colo.

Spencer, A. R., (A-12), owner, A. R. Spencer Co., 413 Hunkin-Conkey Bldg., Cleveland.

Swing, H. R., (M-12), member research staff, Midvale Co.; *mail* 259 South 17th St., Philadelphia.

Tateyama, S. K., (M-11), laboratory assistant, Central Steel Co.; *mail* P. O. Box 155, Massillon, Ohio.

Tepper, C. E., (M-11), president, North West Foundry Co.; *mail* R. F. D. No. 5, Culver Road, Rochester, N. Y.

Thompson, L., (M-11), metallurgical laboratory, U. S. Naval Experimental Engineering Station; *mail* 6 Taney Ave., Annapolis, Md.

Townsend, A. H., (A-12), salesman, Wheelock, Lovejoy and Co., Inc., Chicago.

Tyson, J. D., (M-10), assistant metallurgist, Standard Steel Works, Burnham, Pa.

Vandermast, A. P., (M-11), metallurgical laboratorian, U. S. Naval Experimental Engineering Station; *mail* Colgate, Baltimore County, Md.

Vollmer, C. M., (M-12), foreman, Eaton Axle and Spring Co.; *mail* 13316 Milan Ave., East Cleveland.

Items of Interest

NOTABLE developments in the industrial standardization movement, including important progress in the mechanical and mining industries, and in the safety field, its further extension into managerial and trade association activities both here and in Europe, and steps looking toward it in Latin America, have taken place during 1924, according to an announcement of the American Engineering Standards Committee.

Most of the great firms are now coming to have some definite organization for their standardization work, instead of leaving it as a more or less incidental part of their engineering and production activities. Increasing competition is bound to result in some form of definite organization for the work in the majority of all but the smallest companies. This has already taken place in Germany, where more than 1000 firms have such organizations, some of the larger companies having as many as 100 or even 200 members of their staff devoting full time to such activities. The increase in the number of associations and companies affiliated in the membership of the American Engineering Standards Committee is a notable step in this direction.

This interest on the part of management is shown by the fact that standardization is becoming one of the most important and appreciated activities of trade associations, which are the principal mechanism through which management arrives at collective industrial policies. For example, 150 trade associations are officially participating in the work of the A E S C through accredited representatives.

In all, about 70 standards have been approved by the American Engineering Standards Committee, and 100 others are under way. Of these, 32 have to do with civil engineering, and the building trades; 26 with mechanical engineering; 15 with electrical engineering; 4 with automotive subjects; 11 with transport; 1 with ships and their machinery; 14 with ferrous metals; 15 with non-ferrous metals; 12 with chemical subjects; 2 with textiles; 16 with mining; 5 with the wood industry; 1 with the paper and pulp industry; and 11 projects with topics of a miscellaneous or general character.

A particularly important feature has been the development of the work on mining. Until the very recent past, little had been done in the mining industry. The pioneer work in this field has been done by the U. S. Bureau of Mines, which was first in the field and by the American Mining Congress. Work on no less than ten mining projects has been started under A E S C procedure during the last year. These include codes for rock dusting, mine illumination, ventilation, use of explosives in coal mines, and underground transportation.

The most important piece of work completed by the A E S C in the mechanical field during 1924 was the promulgation of the standard for screw threads, a subject which touches practically every industry. This was worked out in co-operation with the National Screw Thread Commission. Good progress has been made in two other far-reaching subjects, gages and systems of gaging, and pipe flanges and fittings. Parts of the work on both of these subjects are now nearly ready and will be issued soon.

Work on dimensions and tolerance for nuts and bolts is also well advanced. At an informal conference of representatives of the American, Czechoslovakian and German committees, it was recommended that there be held a general international conference looking toward international agreement, so that there may be international interchangeability in regard to wrenches, nuts and bolt heads.

Technical standardization is playing an increasing role in matters of safety. At the recent conference on street and highway safety, called by the Secretary of Commerce, it was strikingly evident that patient detailed standardization of the technical details of traffic facilities and control is essential to the solution of this outstanding problem in public safety. Important examples of such work is that of the A E S C on the unification of colors for traffic signals, and on a code for automobile brakes and brake testing. The importance of the general problem was summarized by Mr. Hoover in the statement that the number of fatalities, 22,600, is one-third as great, and the number of wounded, 678,000 is two and a half times as great as the corresponding American losses in the war.

In the field of industrial safety substantial progress has been made on a program of some 40 codes, most of which are applicable for factories. Thirteen of these have been completed, and work on half of the remainder is well advanced. Codes for logging and saw mill machinery, laundries, and school lighting, and a revision of the code for punch presses were completed and approved during the year.

Standardization activities in foreign industrial countries continue to increase. Among the newer national organizations those in Czechoslovakia and Japan are showing great activity. The former has approved 5 standards, and has no less than 176 other projects under way, and the latter is working on 47 projects. In all there are now nineteen national standardization bodies, as follows: Australia, Austria, Belgium, Canada, Czechoslovakia, Finland, France, Germany, Great Britain, Holland, Hungary, Italy, Japan, Norway, Poland, Russia, Sweden, Switzerland, United States.

Heretofore there has been no very active development of standardization activities in Latin America, and hence the Pan American conference on standardization, which opened in Lima, Peru, on December 23, is a notable event. The general idea of such an undertaking originated with the Latin American countries. While it is not expected that it will be feasible to undertake much of any technical work at the first conference, it is anticipated that the way will be paved for extremely valuable developments.

The Federal Specifications Board has now adopted nearly 300 specifications. These are used as a basis of purchase throughout the Federal government. The A E S C has continued its co-operation in this work, and during the year has circulated more than 100 of these specifications for criticism, in

EMPLOYMENT SERVICE BUREAU

The employment service bureau is for all members of the Society. If you wish a position, your want ad will be printed at a charge of 50c each insertion in two issues of the Transactions.

This service is also for employers, whether you are members of the Society or not. If you will notify this department of the position you have open, your ad will be published at 50c per insertion in two issues of the Transactions. Fee must accompany copy.

Important Notice

In addressing answers to advertisements on these pages, a stamped envelope containing your letter should be sent to AMERICAN SOCIETY FOR STEEL TREATING, 4600 Prospect Ave., Cleveland, O. It will be forwarded to the proper destination. It is necessary that letters should contain stamps for forwarding.

POSITIONS WANTED

FORGE SHOP **FOREMAN** desires position with possible advancement. Experienced in all kinds of hammer forgings, tool dressing, hardening, and heat treating. Also competent of designing dies, tools, fixtures and furnaces for economical productions. Address 2-10.

METALLURGICAL **CHEMIST**—For past 5 years and at present superintendent of plant comprising forging, machine shop, heat treatment, grinding and polishing departments. Educated as metallurgical chemist. 40 years of age. Clean record. Good references. Wishes to change for good reasons, preferably out of the shop. Details upon request. Address 2-15.

METALLURGIST AND METALLOGRAPHIST—University graduate with three years of practical experience in metallurgical department of large steel plant. Capable of conducting thorough investigations on ferrous and non-ferrous metals. Has thorough technical and practical training in metallography of iron and steel. Experienced in the heat-treatment of straight carbon and alloy steels. Location in middle west preferred. Address 2-20.

METALLURGIST with wide experience in ferrous and non-ferrous (alloy) metallurgy and exceptional technical qualifications is desirous of opportunity to organize or control research department in ferrous or non-ferrous (alloy) metallurgical plant or department of metallurgy or physical metallurgy (either as professor or associate professor) in university. Address 1-25.

PRACTICAL **HARDENER** desires position. Has had 6 years' experience. Also has thorough knowledge of metallography and capable of performing microscopic work. Has general knowledge of ferrous and non-ferrous analysis. At present supervisor of heat treating department. Best of references furnished. Salary nominal. Address 1-10.

POSITIONS OPEN

BEARINGS **MANUFACTURER** needs experienced man skilled in annealing and preliminary heat treatment and cold drawing of bearing steels. State full particulars and experience. Address 1-30.

HIGH GRADE **STEEL MANUFACTURER** contemplates installing department for cold finishing wire, small size bars and ribbon steel. Interested in man competent to install and operate department. State full experience. Address 1-35.

POSITIONS OPEN

WANTED young man as assistant to metallurgist, for experimental department of steel mill making tool and alloy steels. Give full details in first letter, including wages expected and why applicant thinks he can fill the job. Address 1-5.

WANTED: Representatives wanted with heat treating experience in the following territories: St. Louis; Birmingham, Alabama; Texas; San Francisco; Pittsburgh; Tulsa, Oklahoma; Buffalo and Cincinnati. Must be capable of earning $5000.00 per year. Address 1-20.

LARGE AUTOMOBILE manufacturer located in Cleveland has position open for assistant metallurgist capable of handling microscopic work and investigations. Excellent opportunity for the right individual. If interested, write at once. Address 1-40.

WANTED

FOR SALE—One Stewart gas fired vertical muffle furnace, practically new. Pratt and Whitney Company, Small Tool Works, Hartford, Conn.

FOR SALE—Bausch and Lomb metallographic microscope. First class condition and ideal for a student. Vertical type. Will sell at a sacrifice. Address 1-15.

FOR SALE—LEITZ METALLOGRAPHIC MICRO-METALLOGRAPHIC EQUIPMENT. Complete. Guaranteed perfect. Attractive price. Address 2-5.

HEAT TREATING EQUIPMENT FOR SALE

2 Gleason Hardening Presses
4-Unit Carburizing Furnace (American Incandescent Heat Co.)
3 Reheating Furnaces (Strong, Carlisle & Hammond Co.)
1 High Speed Furnace (Bellevue Furnace Co.)
2 Pyrometers 1800° F.
1 Twin Filter
1 Twin Strainer
2 Soda Tanks 24" x 24" x 30"
3 Quenching Tanks
1 Storage Oil Tank — 10500 gals. capacity
1 Storage Oil Tank — 15000 gals. capacity
1 Bowser Pumping System
1 Tempering Tank
9000 gals. Houghton's Quenching Oil

Very low prices for immediate sale.

Meachem Gear Corporation
Syracuse, N. Y.

order to determine their acceptability in industry before official adoption by the government.

The third year of the work of Mr. Hoover's Division of Simplified Practice has shown extensive development. In all, 26 simplifications have already been carried through, 10 others are in the final stages, and 45 additional surveys are now under way. Two hundred industrial groups are co-operating in the various projects.

The U. S. Chamber of Commerce and the A E S C are co-operating closely in this work. In general, the Division concentrates upon such eliminations as it is possible to carry out from a survey of statistical production data alone. An exception to this is the work which has been carried out on standardization of lumber sizes and grading rules for soft woods, which constitute the Division's most notable achievement.

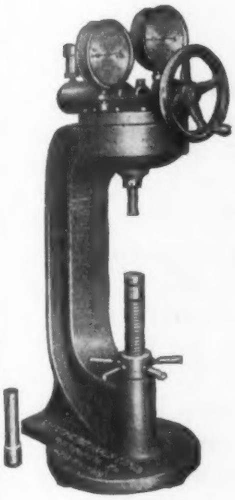
The work on the "Dictionary of Specifications," being carried out by the Bureaus of Standards and of Foreign and Domestic Commerce, is nearly ready for publication. This will consist of a classified list of all of the more important purchase specifications in existence in this country. It has been carried out primarily for the use of public purchasing bodies, to which, as well as to industries in general, it should be of great service.

The co-operation of the Federal Government with industry through the machinery of the A E S C steadily increases; in fact, one or more arms of the government are co-operating in nearly every one of the A E S C projects. The Bureau of Standards and the Federal Specifications Board jointly maintain a liaison officer in the A E S C.

Tate-Jones and Co., Inc., Pittsburgh, have announced that in order to devote their entire effort to the manufacture, development and improvement of their standard line of gas- and oil-fired and electric furnaces, gas- and oil-burners and accessories, an arrangement has been made whereby all sales will be handled by the General Furnace Co., 1015 Chestnut St., Philadelphia. The General Furnace Company will take over the Tate-Jones sales force and they will continue to give the benefit of their experience in the solution of furnace and burner problems.

W. M. Corse, who has been affiliated with the National Research Council in carrying out the financial program to defray the expense of compiling and publishing international critical tables, has become affiliated with the Research service, Investment building, Washington, D. C., in the capacity of vice president and general manager. This bureau offers expert engineering service in the civil engineering field, in nonferrous metallurgy, in personnel administration, informational service in connection with the various departments of the federal government, liaison service for establishing contact with government departments on legislative matters and other contracts pertaining to material purchased by the government and in representation before congress for government, civic, industrial and business organizations. Mr. Corse has had a wide experience in nonferrous metals and alloys, particularly relating to their metallurgy, production and sale.

S. M. Co. Brinell Machine



This machine applies a pressure of 3,000 Kilos to a 10 mm. ball and gives results in Brinell numerals, the international standard for indicating hardness of metals.

The Pressure is applied quickly and evenly, and a patented feature prevents the leakage of the hydraulic fluid.

Pieces from $\frac{3}{16}$ inch to 12 inches may be accommodated. The anvil is adjustable to irregular shaped pieces.

The Standard Machine Adopted by

American Can Co.
American Machine & Mfg. Co.
E. C. Atkins & Co.
Canadian Fairbanks Morse Co.
Carbon Steel Co.
Carnegie Steel Co.
Chicago Pneumatic Tool Co.
Columbia Steel & Shafting Co.
Curtiss Aeroplane & Motor Co.
Dayton Engineering Laboratories
Dominion Steel & Foundry Co., Ltd.
Eagle Pitcher Lead Co.
Firth-Sterling Steel Co.
Henry Ford & Son, Inc.
General Electric Co.
Hughes Tool Co.
Latrobe Electric Steel Co.
Lincoln Motor Co.
Maxwell Motor Co.
McMyler Interstate Co.
Nash Motors Co.
Oliver Chilled Plow Works
Parish & Pool Co.
Piston Ring Co.
Pittsburgh Testing Laboratory
Pollak Steel Co.
Premier Motor Corp.
Railway Steel Spring Co.
Standard Foundry Co
Standard Steel Car Co.
Standard Steel Spring Co.
Studebaker Corp.
Underwriters' Laboratories
Union Switch & Signal Co.
Vanadium Alloys Steel Co.
Westinghouse Electric & Mfg. Co.

And Many Others

Send for descriptive bulletin 103

SCIENTIFIC MATERIALS COMPANY
"Everything for the Laboratory"
PITTSBURGH, PA.

Lawrence Wood has been appointed Detroit district sales manager of the Colonial Steel Company, Pittsburgh, succeeding the late George W. Hampshire. Mr. Wood was formerly Pittsburgh district sales manager of the company, and the vacancy created by his promotion and transfer has been filled by the appointment of R. M. Brushingham.

James J. Armour, foundry superintendent Studebaker Corp., South Bend, Ind., since Feb., 1914, died in his home in that city Dec. 2 at the age of 48. Mr. Armour was born in Oshawa, Ont., Jan. 25, 1877, and commenced his foundry career as a wire boy in a coreroom at the age of 14. Later he entered the employ of the Walkerville Malleable Iron Co., Walkerville, Ont., where he was advanced to the position of foreman, and remained in that capacity for 2 years. He served for varying periods of time as foreman of the Lancaster Foundry, Lancaster, N. Y.; the Standard Foundry, Detroit, and the Flanders Co., Pontiac, Mich., before he first joined the Studebaker Co. in Detroit as trouble man. In 1914 he was promoted to the position of foundry superintendent in the South Bend plant of the corporation. He was active in the design and construction of the immense new foundry recently placed in operation and by peculiar coincidence was buried on the day the last small heat was poured in the old foundry prior to its actual abandonment. He was a member of the South Bend chapter of the Society.

The Cleveland district section of the Association of Iron and Steel Electrical Engineers held a meeting on Monday, January 12th, 1925, in the Electrical League Rooms, Hotel Statler, at which time R. F. Crump, engineer, Stroh Steel-Hardening Process Co., Pittsburgh, gave an interesting address entitled, "Steel Treating and Its Value to the Steel Industry."

The Aluminum Company of America have recently published the third edition of their bulletin "Pistons," which they state, is designed to be a practical reference book on aluminum pistons, particularly adapted to the use of dealers, salesmen, garage men, mechanics and repairmen.

The Queen City Steel Treating Company and the Metallurgical Service Company, both of Cincinnati, have combined their business activities and are now operating under the name of the Queen City Steel Treating Company. E. P. Stenger, metallurgical engineer and president and manager of the Queen City Steel Treating Company, is the active head of the corporation. N. M. Salkover, who formerly conducted the Metallurgical Service Company and who is a graduate metallurgical engineer, is a member of the Queen City organization. In addition to operating a modern commercial heat treating plant the company now sells heat treating equipment and supplies. This company is Cincinnati district representative for the American Gas Furnace Company, Case Hardening Service Company, Chas. Engelhard, Inc., General Alloys Company and other manufacturers in this field.

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